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ENERGY RESEARCH
Directions and Issues for the Developing Countries

2nd draft

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FOREWORD

1m (p. 7, #2)
The Energy Research Group was convened in August 1983 with the following terms of reference:

(A) To carry out a thorough review of energy-related research and technology relevant to developing countries.

(B) To survey the existing and likely capability in developing countries to conduct, finance, diffuse and use energy research and development.

(C) To survey the energy-related research and technology in developed countries, its relevance to developing countries, the terms on which access to it is available, and ways of using it for the greatest benefit of developing countries.

(D) To disseminate the views of the Group as well as its members, to invite informed opinion and to provoke discussion on the energy-related issues facing the developing countries and the research results on them.

(E) To recommend the priorities in the conduct and utilization of energy-related research in the light of their findings regarding resources for the consideration of decision-makers, researchers and other interested parties, and

(F) To recommend means by which the allocation of resources available for energy-related research can be determined and improved, nationally and internationally.

2m (p. 8, #5)
The survey of research commissioned by the Group in fulfilment of the terms of reference (A) and (C) consisted of 103 reviews. Whilst many of them are referred to in the present report, this report is neither a summary of them nor a review of research. We hope the sponsors will make the approved reviews widely available, not only because they form the background of this report but also because they are a valuable survey of energy research of interest to researchers as well as practitioners.

3m (p. 11, #15)
It has not been possible within the resources of the Group to fulfil the term of reference (D) and to disseminate our views or to invite discussion. We recognize the importance of discussion, especially to test our views, and would welcome it if this report or our review papers were to lead to more lively discussion of the serious energy-related problems of developing countries.

4n
This report covers terms of reference B, E and F, and needless to say, the adequacy of its coverage is constrained by the time and the resources available. The research funds provided by the International Development Research Centre and the United Nations University were generous. But the field of energy research is so vast and the diversity of developing countries so great that a comprehensive and accurate identification of research capability and research priorities for all developing countries would have been unrealistic, if not foolhardy, even had our resources been considerably larger. What we have tried to do is to point out the promising directions, not to lay down a master plan.

5m (p. 9, #10)

The information we have used is mostly published information: unpublished information is much more difficult to survey. Our coverage of English language material has been comprehensive. Our regional surveys covered literature in Spanish, Portuguese, Chinese, Korean and Indonesian; we also tried to cover literature in French and German. Literature in Russian remains an important gap in our survey.

6n

For reasons of time and space we imposed the following limitations on ourselves:

(i) Whilst we have tried to link major research problems to the developing countries for which they are most relevant, we have refrained from going into regional and national details.

MM

(ii) We have tried to go just deep enough into technologies to make a broad judgment of their end-uses, their appropriateness for those uses, their relative priorities and importance, and the promising directions of research; to go deeper into technological complexity, however desirable, was not possible given the breadth of our mandate.

(iii) Even reaching such a broad judgment is difficult where information on technologies is confidential or proprietary, or where research has not gone far enough to provide a basis for judgment. In a number of such cases we have refrained from making a judgment.

7n CS MM

It is in the nature of a group like ours and of our task that all of us need not agree on everything in this report. But none of us has a basic disagreement on any major aspect or recommendation in the report. The minor reservations, qualifications, and doubts some of us may have on certain specific propositions are not always spelt out in detail because we feel that we also owe a duty to our readers to keep the report clear and simple. We have no hesitation in identifying ourselves with this report, and would stand by all its essential propositions.

8n

We would like to thank the International Development Research Centre and the United Nations University for making possible this exciting intellectual experiment. The hard work and dedication of our secretariat enabled us to achieve much more than we had initially hoped for. The contribution of our consultants, authors and referees is obvious, but we would like to express our special thanks to all our professional colleagues who gave us unstinting help, often at short notice and for little or no reward. Finally, we would like to thank the directors and staff of IDRC's regional offices in Singapore, Bogota, and Delhi and the UNU office in Tokyo, for their magnificent hospitality.

I. THE TASK AND THE APPROACH

9m (p. 1, #1) MM

The Energy Research Group first met in August 1983. The members came from a wide range of backgrounds (see Appendix 1). Some of us could be classified as scholars, professionals, administrators, politicians; most were somewhere in between. We found ourselves at various times to have been involved in teaching, research, politics, journalism, management, and unemployment. There were only two elements that united us: we were nationals of developing countries working in developing countries, and we had, at some time in our lives, taken a serious interest in some aspect of energy -- more serious than just forming a judgment or making a pronouncement. Most of us had either studied, taught or managed it. As will be evident, these common features shaped our conception of what we could and should do.

10m (p. 1, #2) MM AR

Active public concern with energy is over a decade old; in these years much has been written about what developing countries should do or have done to them (for instance, United Nations 1981; World Bank 1981, 1983a; World Bank and Food and Agriculture Organization 1981a; Bhagavan and Carlman 1982; Mwandosya 1983; Commission of European Communities 1984; Goldemberg et.al. 1985). The Group had to ask itself what, if at all, it could add to the considerable body of deliberations and recommendations that had preceded it.

11n

The Group had two basic models to follow. One is a purely professional review of research needs based on the technical gaps in knowledge (for an excellent example relating to combustion research, see Smoot and Hill 1983). This approach was not really applicable to our subject, which has neither a well-defined peer group nor a broad consensus among the principal practitioners. The second model is a social and political comment. This model was indispensable, since there is no way of prescribing research priorities for development without bringing in social and political criteria. But the Group could not stop there; both the composition of the Group and the conditions of its formation required that a professional judgment be combined with a sociopolitical one. Thus the Group had to prepare its own mixture of the two models. The approach it adopted calls for some explanation.

1. Points of Departure

12m (p. 2, #1) MM

Pathology of research: To begin with, the Group could not take its terms of reference literally and limit itself to setting energy research priorities. As initiators and practitioners of research in developing countries, we were all too aware of its pathology, and were convinced that unless the effectiveness of research institutions in developing countries was improved, and unless they were integrated into the productive and policymaking processes, setting research priorities would be quite ineffective. Whilst our views on research may not be definitive, we have felt compelled to set down the beginnings of a diagnosis in Chapter II.

13e (p. 2, #2) AK

Research trajectories: The point of setting research priorities is to lead resources -- researchers, funds, equipment -- towards desirable or promising subject areas. But such a redirection of resources can lead to waste if the research is wrongly directed. Research is often a venture into the unknown; it can go wrong in a number of ways. Research problems are conceived in terms of paradigms current among communities of researchers -- paradigms which are not always appropriate for efficient solutions. Research is partly a social phenomenon, and communities of researchers often display elements of crowd -- or hunting-pack -- psychology: pioneers who tackle new problems or try out new methodologies and instruments are often followed by hordes of imitators. This bandwagon effect is, for instance, to be frequently seen in the influence exercised by developed-country paradigms on research in developing countries; it is reinforced in this case by the considerably larger material and social rewards to research published or recognized in industrial

countries (Cooper 1973). Expenditure on research is an investment, and is susceptible to the same forces that cause waste in investment, such as possibilities of profit and aggrandisement. These are some of the sources of waste that would persist even if priorities were correctly set.

14m (p. 3, #3) AR

Hence the Group felt that as researchers we should point not simply towards areas of priority research but also towards the promising directions or approaches. Lest we were in danger of forgetting the risks of such an undertaking, we reminded ourselves of Werner Siemens's state-of-the-art review of electricity research. The founder of the well-known power equipment firm, Siemens und Halske, was a considerable inventor in his own right. After reviewing experiments all over the western world (including a battery-powered boat floated by Jacobi on River Neva in Russia), Siemens concluded that batteries were unlikely to serve as a basis for the widespread use of electricity, and concentrated on the development of 'magneto-electric machines', or dynamos. His judgment has been justified by the insignificant role of batteries after a hundred years of development. But he also concluded that lighting with carbon or metal wires was impractical since "the light so generated is too weak, requires much electricity and labour, and can hardly be called electric light" (Siemens 1880: 21); he therefore concentrated on the development of electric candles and lighted the German Parliament with them. On 21 October 1879 -- almost as Siemens wrote those words -- Edison put a carbon filament inside an evacuated bulb and demonstrated an invention which put arc lights to sleep forever.

15m (p. 3, #4) JG

Thus we make our assessments of promising directions of research with modesty and caution, and claim no infallibility for them. We have also tried, perhaps unsuccessfully, to stay within our own expertise and not to speculate. This means that we have not been equally specific in all areas. But we have nevertheless ventured to make judgments which we hope make research more effective.

16m (p. 3, #5) CS MM

A lay view: The Group decided that energy research priorities should be derived from the place of energy in the development process, and not from any intrinsic characteristics of energy. It thus decided to bring under its purview research that energy analysts do not always cover -- for instance, research on human energy, and on energy-using devices. In this respect it shares the focus on energy demand common to energy policy research, though not to all energy technology research.

17m (p. 3, #5)

Though all were academic or professional specialists, the members of the Group tried to transcend their technical standpoints and to reach a broad consensus, to supplement their technical knowledge with an awareness of the socioeconomic choices facing developing societies and of the conflicting interests that constrain those choices. They discussed and tried to reach an agreement on the ideological assumptions that should govern their common socioeconomic judgments; these assumptions are described in section 3 of this chapter.

18m (p. 4, #6) AR

All forms and uses of energy: Following its mandate the Group tried to cover all forms of energy as well as all uses. We have ignored energy forms which are unlikely to be significant in the medium and the long run (e.g., ocean thermal energy conversion). We have left out a number of energy uses or user devices (e.g., turbines, jet engines), largely for lack of time, but also sometimes because research and development is confined to a small number of producers and is difficult to observe from outside.

19e (p. 4, #7) JG MM

Unlike many scholars, including some of our reviewers, we have not taken any position on the question of renewable vs. exhaustible resources. The use of exhaustible resources involves their allocation amongst succeeding generations. It entails a value judgement which no simple optimization rule can help us avoid. The Hotelling principle, that the net price (excluding the extraction and production costs) of an exhaustible resource must increase at a rate equal to the rate of interest, is not very helpful since there is no easy way of making intergenerational comparisons of utility (see Umaña 1984). However, the moral choice has to be made by

those who determine the intergenerational decision. The bulk of exhaustible resources is consumed by industrial countries, and given the organization of industrial markets, lower consumption of fossil fuels by developing countries now is by no means likely to make more of such fuels available to future generations in those developing countries. Thus the choice is not the developing countries' to make; nor is the moral judgment that the choice imposes.

20e (p. 5, #9) CS DF

This does not mean, however, that the developing countries will not suffer the consequences of resource exhaustion. If, therefore, efforts come to be made to regulate the rate of global resource exhaustion, the developing countries have a clear interest in contributing to them. Further, countries that exploit any exhaustible resources (including fossil fuels) for their own use or exports, have to decide how rapidly to exhaust the resources. They have a researchable problem of intertemporal choice in resource exploitation, whether they treat it as one of intergenerational allocation, or balance-of-payments management or analyze it in any other way they choose. It is a crucial problem for countries with exhaustible resources to export. Multinational corporations, banks and other investors with high discount rates favour a high rate of exploitation which is against the interests of future generations and which can cause structural changes that are unsustainable once the resources are exhausted. Governments of developing countries must guard the interests of future generations in this conflict of interest.

2. Basic Premises

21n JG

To sum up the philosophy behind this report, the Group has tried to propagate an **integrated approach** to energy problems. As a subject advances, researchers progressively subdivide it and go progressively deeper into ever more narrowly defined problems. Energy studies are a hybrid of many disciplines at present, and each discipline brings to them its own concepts and methodologies. But at the present stage it is important for the developing countries that energy problems should be defined in the broadest terms, and that new concepts, theoretical formulations and methodologies should be developed. So we favour a coordinated and systematic exploration of the hidden interconnections between energy and other variables -- a preference that is illustrated for instance by our stress on energy-economy relationships, integrated national energy planning and the influence of location patterns on energy consumption.

22n JG

Next, the Group argues for the study of energy resources and technologies in the context of the demand for them. This has two major implications. First, demand for energy must be treated as an active policy variable, as a potential source of solutions to energy problems on par with supply and technology. It is possible to treat demand as an exogenous variable, determined by the trends in output, incomes and prices, and to ask what energy sources can meet this projected demand (see, for instance, Wilson 1977, Greene and Gallagher 1980). This type of formulation begins to lose relevance even for the richest industrial countries once real costs of energy begin to go up; it is still less appropriate for such developing countries in which the supply of energy is likely to be further constrained by limited investment capacity or a strained balance of payments. For them, demand for energy must be regarded as a variable instead of a parameter: we must ask, what style of development will permit the greatest rise in standards of living consistent with constraints to energy -- or indeed, any other constraints? Whose requirements must have higher priority? Which possibilities of interfuel substitution and energy saving can be exploited to harmonize energy demand and supply? How do technologies available to serve the same use compare in terms of their costs and energy efficiency? Thus, demand for energy can be regulated and managed, and the possibilities and limits of **energy demand management** are a prime subject for research in developing countries.

23n JG
Second, energy resources and technologies must be studied in the context of their uses, and the alternative resources and technologies that can serve the same use must be studied together. In other words, there are possibilities of **interfuel substitution** in most energy uses, these possibilities determine the competitiveness of energy sources in those uses, and prospects of competitiveness must play a decisive role in decisions on research on a specific resource.

24n JG
Finally, energy saved adds to supply just as energy produced does. Research on ways of saving energy has advanced less far and has greater potential than research on energy production and greater relevance to developing countries. Whilst developing countries are small users and even smaller producers of large-scale forms of energy, their stocks of boilers, for instance, run into thousands, of engines and motors into millions. Small improvements in the efficiency of these devices can make a large difference to the energy consumption of developing countries. Thus **energy conservation** deserves high priority.

25me (p. 6, #15)
Unfortunately, the body of research on many such devices has not advanced to the point where we could confidently identify the promising directions of research. They are not the only field in which the Group found itself plumbing the depths of uncertainty; there are many fields in which our judgment is tentative and imperfect. We therefore regard this report, not as a verdict, but as an education, and offer it as a contribution to the processes of debate that guide national and international decisions. We expect to learn as much from the debate as we did from writing this report.

3. Normative Assumptions

26m (p. 13, #1) AK MM
The determination of energy research priorities calls for a utilitarian approach, for a review of the proximate practical objectives rather than the promise or fascination of research. At the same time it was impossible for the Group to take a narrowly client-oriented view both because the potential clients -- governments, funding agencies, producers, etc. -- were many and because their objectives were subject to debate. The best that the Group could do, therefore, was to work with a set of goals that would be broadly shared in developing countries. Of these ideals, which are discussed below, some may look as universally laudable as motherhood, others as polemical as zero growth. But some of the judgments expressed in this report will inevitably generate controversy. We welcome controversy as the thorny path to truth, but to be fruitful controversy should start with the same initial premises. We thought it best to articulate ours, first in order to help in the process of our own consensus, but then also in the hope of steering debate in more constructive directions.

27m (p. 13, #2) MM
In the centuries preceding the rise of modern industry, the comfort in which a people lived and the labour they had to do to gain their living depended on the relationship between man and land. It is self-evident that a surplus of food beyond the consumption of the food-producing population was essential at all times to the existence of urban concentrations of people who did not produce their own food. Where high levels of fertility were achieved or where there was an abundance of fish, fowl and fruit, the people lived well or had ample leisure; under harsher conditions they had to work harder for a more meagre living.

28o (p. 14, #3)
In regions where a surplus beyond the subsistence requirements of the food-producing population could be produced, a part of the population pursued other occupations such as trade, government, religion and warfare: some thereby achieved considerable wealth and prosperity. Thus mechanisms were built into some preindustrial societies that generated economic inequality.

29m (p. 14, #4) MM

The innovation of modern mechanical techniques led to enormous increases in the productivity of human labour. They made possible concentrations of wealth and income that were unimaginable in the preindustrial world; but they also, through the reinvestment of that wealth in activities that required labour, raised the incomes of the working populations. This process of economic growth by now almost encompasses the greater part of the populations of the countries which are considered industrialized.

30m (p. 14, #5) MM

In the rest of the world the processes of growth of productivity and incomes have affected only a part -- often a small part -- of the population, and have generated large differences in wealth and lifestyle between those who have benefited from the global tide of productivity growth and those who have not. Amongst those who have not, are to be found levels of poverty and distress which are no longer inevitable, and which constitute a blot and a shame in view of the levels of prosperity of their neighbours near and distant.

31n

We strongly believe in the need for **development.** A significant expansion of the output of goods and services is obviously desirable for developing countries. Energy, as we stressed earlier, is an intermediate product, and concern about it makes sense only in the context of the need for greater production and consumption.

32n CS

But we also believe that in developing countries there are mechanisms that lead to an uneven distribution of the benefits of growth. Inequalities arising from the concentration of property are as prevalent in developing as in industrial countries, and the forces that increase wages and reduce inequality are not as strong in developing countries as in some industrial countries. But there are other disequalizing forces that are characteristic of, or stronger in, developing countries. Ownership of industry and business tends to concentrate in narrow social groups. Political power is held by small groups and converted into economic power. Access to education is unequal, and there are wide variations in the quality of the education available to the rich and the poor. Growth is confined to the commercialized sectors of the economy, and leaves people engaged in subsistence gathering, hunting and agriculture untouched. Land is an important avenue of enrichment, and its ownership is not open to large segments of the rural population. In urban areas, poor housing, insecurity and uncertainty of employment combine to deprive the poor of the possibilities of asset accumulation. The consequence of all these forces is evident in the widespread poverty, distress and squalor even in some of the most prosperous and dynamic of the developing countries. These tragedies of development are, in our view, avoidable, and their extreme features are remediable even within the present resources of developing countries.

33me (p. 14, #8)

We do not believe that poverty or inequality can be removed or even significantly reduced by action in the field of energy alone. But most types of action have a technological component, including action to influence poverty or inequality, and all technology has an energy component. The implications of action for income distribution and the provision of basic needs can be important, should be explored and should be considered in formulating energy policies. Further, action in the field of energy can improve productivity and provide the basis for improvements in income distribution and in the quality of life. More important, extremes of poverty and inequality introduce elements of instability and brittleness in societies which make their smooth and rapid development impossible. This is why **poverty alleviation** must form an essential component of development policy, of which energy policy is a part.

34n CS DF

The advent of modern industry has led to the emergence of a large number of new products, activities and occupations, many of which are largely confined to industrial countries. This specialization, together with the concentration of industrial production in industrial countries, gives them considerable influence on

the fortunes of developing countries -- influence exercized not only by the governments but also by large transnational corporations with headquarters in industrial countries. It is reasonable to expect that these governments as well as corporations should exercise their power over developing countries with fairness and justice, for instance in trade, finance and technology transfer. In this sense, we favour a **fairer world economic order.**

35m (p. 15, #10) MM

But we also recognize that the world is divided into nation-states; and whatever the level of international assistance, the development of a nation-state depends largely on efforts of its own people and within its frontiers. It is therefore essential for the development of countries that they should internalize certain activities and capabilities: that they should rely on themselves in a few essential respects. On what precisely these are, and where the line is to be drawn between self-reliance and autarky, there is room for difference of opinion. But there is a greater consensus on the existence of a class of essential activities. The capacity in the government to take independent decisions in energy policy in the national interest is an obvious example. From it follows the need for the research capacity required to make informed decisions, and the productive capacity to sustain and utilize research. Thus **self-reliance** is the shorthand for the economic and technological adjuncts of national sovereignty.

36o (p. 16, #9)

It is impossible to consider large questions of policy, including energy policy, without becoming aware of externalities. The use of fossil fuels by some harms others in various forms such as acid rain and pollution. We believe that the disutilities and inequities arising from economic activities should be brought firmly into the calculation of net benefits and that such activities should pass the test of **environmental soundness.**

37o (p. 16, #10)

Externalities arise not only between people living together in this world but also between generations. For instance, the quantity of fossil fuels available on this planet is strictly finite; whoever uses any today reduces the available potential supply to the coming generations (Georgescu-Roegen 1976). Whilst we do not conclude from this fact that there should be a rapid shift from exhaustible to renewable resources, we must stress the need to take account of the **interests of coming generations.**

38m (p. 16, #13) CS JG

We share a preference for **efficiency** in the sense that if an activity can be undertaken with a lower resource input it should be. This preference may sound trite; it is also unspecific since there is no unique measure of efficiency. Measurement in terms of a single factor -- for instance, labour productivity -- can be misleading where there are a number of inputs; and there is an infinite number of ways of weighting such inputs to get a measure of efficiency. Weighting them by their prices is a convenient convention, but prices are not invariant. In particular, many developing countries are import-dependent in energy and face extremely unequal chances of expanding exports. The resulting variations in the shadow cost of imports may make research on, and investment in, import substitutes including energy worthwhile in some developing countries even when international costs at current exchange rates do not support them. It is necessary to take a long view in such decisions; for instance, a country that expects its balance of payments to worsen may take advance action to develop alternative energy techologies even before they become economic at the ruling exchange rate. More generally, a usable concept of efficiency must take account of multiple inputs and must be adapted to local conditions and national objectives.

II. RESEARCH AND ITS ENVIRONMENT

39m (p. 18, #1) AR CS

This chapter is focussed on energy research. But much that is said here will have wider application.

40m (p. 18, #2) AR

Research has two features which are crucial but difficult to define: utility and quality. If it is to be subjected to any social or economic evaluation, research must directly or indirectly serve a practical use; but that is not enough. Research that leads to wrong conclusions can do harm, and the more important its application, the greater the harm it can do. Hence research has to be both useful and sound.

41o (p. 18, #3)

Research is an intermediate input which may be used in policy formulation, production or consumption. In these activities, it must either reduce risks attaching to decisions, or expand options, or reduce costs, or improve the quality of goods and services. Its usefulness can only be judged in terms of one or more of these consequences.

42o (p. 18, #4)

However, all of these consequences are in spheres outside research. Thus the benefits of research are contingent on the downstream users -- policymakers, producers or funding agencies. They must be skilled at using research and at translating it into practical decisions; and this requires some training in the disciplines that go into research. We shall stress the importance of informed users in generating good research in various industries, notably oil and power, but the point is more general: the broader the training of research users, the greater the use they will be able to make of research. For instance, surface tension may appear to a lay mind as too abstruse a subject to be of practical use, but it has at least two applications even within the field of energy, namely in the prevention of scaling in power plant boiler tubes, and in economizing hot water in washing and cleaning.

43o (p. 19, #5)

As important as the informed user is the informed director of research; but he needs to be informed for a different reason. Knowledge is not organized on any principle of utility but on the basis of theories and tools. Hence any practical problem requires a decision on what field of knowledge should be applied to it, and has often to be divided up into subproblems that can be tackled by individual researchers or small teams; conversely, the results obtained by them have to be integrated into practical solutions. This subdivision of problems and integration of results calls for a special expertise in the director of research.

44o (p. 19, #6)

An attempt is made in the following sections to spell out the implications of these principles in terms of the principal institutions that use and produce research.

1. Governments

45o (p. 20, #1)

Governments do or commission a great deal of policy-oriented research; much more research which they do not pay for is done for them by researchers in search of wise and powerful rulers. Whilst their wisdom and power vary greatly, governments are basically institutions for resolving conflicts and regulating competition in the political field. The rules they follow in the resolution of conflicts range from extreme laissez-faire to comprehensive intervention. But whatever their ideological complexion, energy-related problems have forced almost all governments into action into many fields, such as the following:

46m (p. 20, #2) AK CS

The balance of payments: Management of foreign exchange reserves is always in government hands. The rise in the price of oil forced a number of developing-country governments to take a variety of corrective policies such as import regulation, import substitution, export promotion, exchange rate variation, international borrowing and lending. Whilst oil prices have eased, a number of developing-country governments continue to have serious payments problems either on account of oil imports or on account of debts contracted to pay for oil or energy-related equipment. Insofar as energy imports or exports make the balance of payments of a developing country vulnerable, it will have to pursue active external economic policies.

47o (p. 20, #3)

National resource management: For energy resources which are depletable or have a limit to sustainable yields, governments have to take decisions on who is to exploit them, at what prices, how fast, how they should be taxed or subsidized, how they are to be rationed in the event of a shortage, and how economic rents should be appropriated.

48e (p. 20, #4) CS MM

Gestation lags and lumpiness: Some types of energy-based production (e.g., development of coal mines, oil exploration and production, construction of power plants), as well as changes in consumption patterns that require the replacement of equipment stocks, take many years, and have to be planned well in advance. The large minimum size of certain types of energy investments also raises problems of matching the time patterns of demand and supply. Even if they are privately owned, investment in them is influenced by entrepreneurial expectations of return, which are strongly influenced by government policies. Thus government action based on a forward view can make energy investments more timely and less costly.

49m (p. 21, #5) CS

Essential needs: Essential commodities including energy have to be shared out in the event of shortage, or if a rise in their prices causes widespread hardship.

50m (p. 21, #6) CS

Monopolies: Natural or otherwise, monopolies call for regulation to prevent high prices or inefficiency. Monopolies, including state-owned ones, are common in the energy sector. In addition, a number of countries face monopolies in the import of oil and monopsonies in the export of resources.

51m (p. 21, #7) CS

Conflicts of interest: Large projects such as dams, mines and transmission lines affect so many people that governments must step in as arbitrators between social and economic interest groups. Whilst the general principle of gainers compensating losers is well understood, the quantum of compensation and the mechanisms for raising and distributing it permit many variations.

The need for energy policy analysis

52n MM

The pervasive and critically important role of energy in national economies indicates that the identification of energy issues and energy policy development are important areas of study by governments, researchers, and the development community. Energy policy analysis, planning and management must be improved in order to ensure that major energy policy initiatives, programmes and projects which are being implemented have the greatest beneficial impact and effectiveness. Since most developing countries devote at least one-third of public sector investments to energy, and the oil importers often spend 50 per cent or more of their export earnings on petroleum imports, even small improvements in the efficiency of energy supply and utilization can have a large impact on macroeconomic policy.

53n MM
Energy planning, broadly interpreted, denotes a series of steps or procedures by which the myriad interactions involved in the production and use of energy may be studied and understood within an explicit analytical framework. Planning techniques range from simple manual methods to sophisticated computer modelling. The complexity of energy problems has forced increasing reliance on the latter approach. Energy policy analysis is the systematic investigation of the impact of specific energy policies or policy packages on the economy and society, at all levels. Energy management, which includes both supply and demand management, involves the use of a selected set of policies and policy instruments to achieve desirable energy and economic objectives.

54n MM
An important aim of energy research in Third World countries must be to upgrade the quality of energy planning, policy analysis and management. In particular, such studies must also focus on methods of enhancing the effectiveness of energy policy implementation. In order to better understand the role of energy research, we begin by identifying below, some of the broad goals of energy policy as seen from the national perspective.

55n MM
The broad rationale underlying national level planning and policymaking of all kinds in the developing countries is the need to ensure the best use of scarce resources in order to further overall socioeconomic development and improve the welfare and quality of life of citizens. The economic management of national resources is a part of the minimum business of national governments. Economic plans are a means of providing internal consistency in macroeconomic decisions, and of introducing rational calculation into the division of resources amongst them. Energy planning in particular is therefore an essential part of national economic planning, and should be carried out and implemented in close coordination with the latter (Munasinghe 1980c). However, the word planning, whether applied to the national economy or the energy sector in particular, need not imply some rigid framework along the lines of centralized and fully planned economies. Planning, whether by design or deliberate default, takes place in every economy, even in those where so-called free market forces reign supreme. In energy planning and policy analysis, the principal emphasis is on the detailed and disaggregated analysis of the energy sector, its interactions with the rest of the economy, and the main interactions within the various energy subsectors themselves.

56n MM
Energy policy analysis and planning must be developed to meet the many interrelated and often conflicting overall national objectives as effectively as possible. Specific goals usually include: (a) determining the detailed energy needs of the economy and meeting them to achieve growth and development targets; (b) choosing the mix of energy sources to meet future energy requirements at lowest costs; (c) minimizing unemployment; (d) conserving energy resources and eliminating wasteful consumption; (e) diversifying supply and reducing dependence on foreign sources; (f) meeting national security and defence requirements; (g) supplying the basic energy needs of the poor; (h) saving scarce foreign exchange; (i) identifying specific energy demand/supply measures to contribute to possible priority development of special regions or sectors of the economy; (j) raising sufficient revenues from energy sales to finance energy sector development; (k) price stability; (l) preserving the environment, and so on.

57n MM
We discuss below several areas in which further research can make a significant contribution to energy policy development and implementation in the Third World.

Integrated national energy planning

58n MM
Because of the many interactions and nonmarket forces that shape and affect the energy sectors of every economy, decisionmakers in an increasing number of countries

have realized that energy sector investment planning, pricing and management should be carried out on an integrated basis, e.g., within an integrated national energy planning (INEP) framework which helps analyze the whole range of energy policy options over a long period of time (Munasinghe 1980a, 1980b).

59n MM

The development of the concepts and methodology of INEP and policy analysis, and its subsequent application, can be traced to the energy crises of the 1970's. Before this period, energy was relatively cheap, and any imbalances between supply and demand were invariably dealt with by augmenting supply. The emphasis was more on the engineering and technological aspects. Furthermore, planning was confined to the various energy subsectors such as electricity, oil, coal, etc., with little coordination among them.

60n MM

From the mid-1970's onwards, the rapidly increasing costs of all forms of energy, led by the world oil price, stimulated the development of new analytical tools and policies. First, the need became apparent for greater coordination between energy supply and demand options, and for the more effective use of demand management and conservation (Munasinghe and Scott 1982; Munasinghe 1983b). Second, energy-macroeconomic links began to be explored more systematically. Third, the more disaggregate analysis of both supply and demand within the energy sector offered greater opportunities for interfuel substitution (especially away from oil). Fourth, the analytical and modelling tools for energy subsector planning became more sophisticated (Munasinghe 1979). Fifth, greater reliance was placed on economic principles, including the techniques of shadow pricing in the developing countries (Munasinghe and Warford 1978); Munasinghe 1980b).

61n MM

INEP makes use of all these separate threads. Some early attempts were made, particularly in the second half of the 1970's. It was soon recognized that the constraints imposed by limited data, skilled manpower and time, posed formidable problems, especialy in Third World countries. Many of the early models were designed to be as all-encompassing as possible, and therefore proved to be too large and unwieldly. On the other hand, more specific models tended to overlook important energy sector or macroeconomic linkages. Finally, most models were not policy-oriented, and were often treated as mere academic exercises. This initial learning process led to a more hierarchical analytical framework that recognizes at least three distinct levels of analysis, including: energy-macroeconomic, energy sector and energy subsector, as well as the interactions among them. This approach also gives a better policy focus. More recently, the availability of microcomputers has provided Third World analysts with a relatively cheap, powerful and flexible tool to develop and apply some of these ideas (Munasinghe et al. 1985).

62n MM

Coordinated energy planning and pricing require detailed analyses of the interrelationships between the various economic sectors and their potential energy requirements on the one hand and of the capabilities and advantages and disadvantages of the various forms of energy such as electric power, petroleum, natural gas, coal and traditional fuels (e.g., firewood, crop residues and dung) to satisfy these requirements on the other. Nonconventional sources, whenever they turn out to be viable alternatives, must also be fitted into this framework. The discussion applies both to the industrial and the developing countries. In the former, the complex and intricate relationships between the various economic sectors and the prevalence of private market decisions both on the energy demand and supply sides, make analysis and forecasting of policy consequences a difficult task. In the latter, substantial levels of market distortions, shortages of foreign exchange as well as human and financial resources for development, larger numbers of poor households whose basic needs somehow have to be met, greater reliance on traditional fuels, and relative paucity of energy as well as other data, add to the already complicated problems faced by energy planners everywhere.

63n MM

The scope of integrated national energy planning (INEP), policy analysis and supply-demand management may be clarified by examining the hierarchical framework depicted in Figure 1 (Munasinghe and Rungta 1984). At the highest and most aggregate level, it must be clearly recognized that the energy sector is a part of

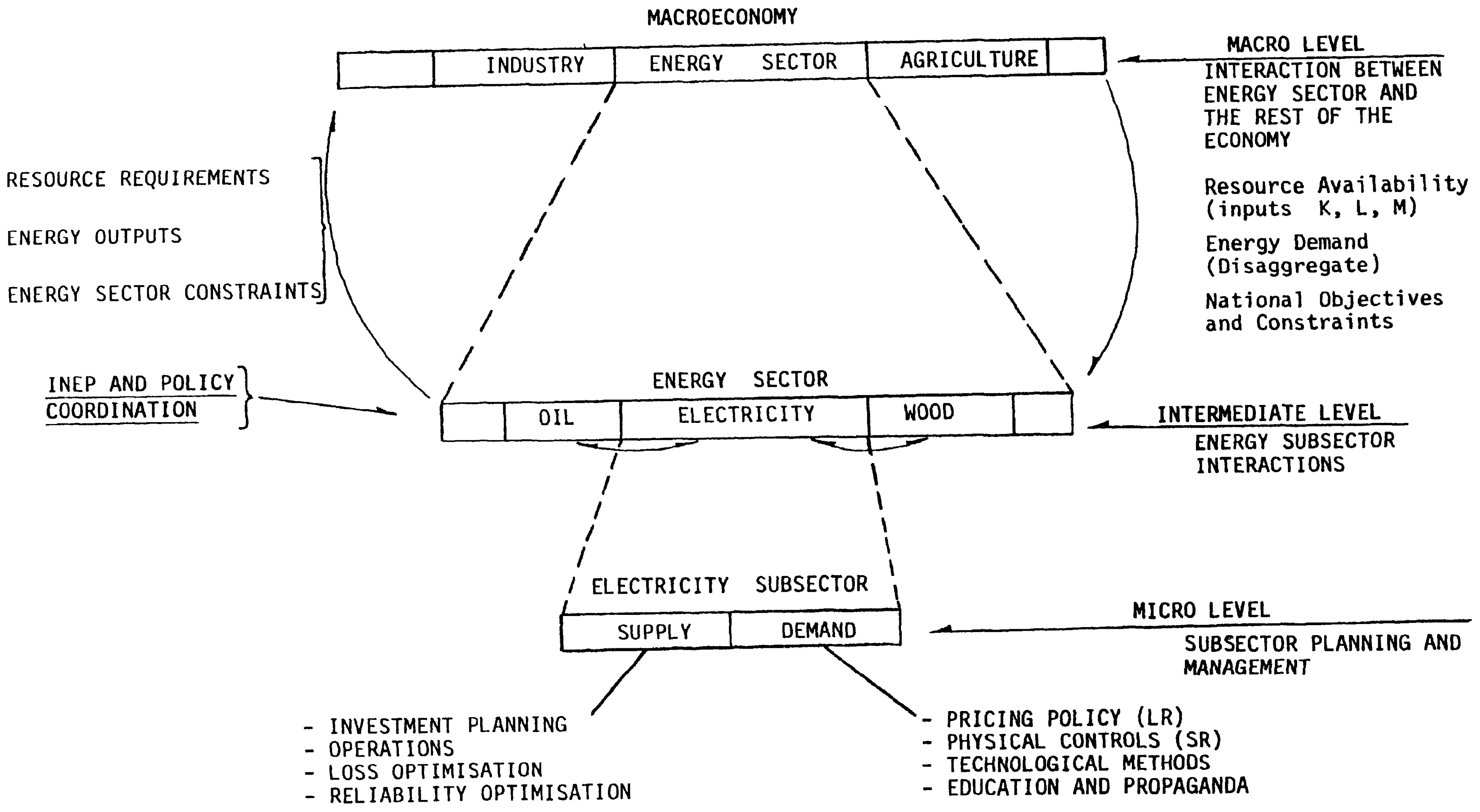
MACROECONOMY
INDUSTRY
ENERGY SECTOR
AGRICULTURE
MACRO LEVEL
INTERACTION BETWEEN ENERGY SECTOR AND THE REST OF THE ECONOMY
Resource Availability (inputs K, L, M)
Energy Demand (Disaggregate)
National Objectives and Constraints
RESOURCE REQUIREMENTS
ENERGY OUTPUTS
ENERGY SECTOR CONSTRAINTS
INEP AND POLICY COORDINATION
ENERGY SECTOR
OIL
ELECTRICITY
WOOD
INTERMEDIATE LEVEL
ENERGY SUBSECTOR INTERACTIONS
ELECTRICITY SUBSECTOR
SUPPLY
DEMAND
MICRO LEVEL
SUBSECTOR PLANNING AND MANAGEMENT
- INVESTMENT PLANNING
- OPERATIONS
- LOSS OPTIMISATION
- RELIABILITY OPTIMISATION
- PRICING POLICY (LR)
- PHYSICAL CONTROLS (SR)
- TECHNOLOGICAL METHODS
- EDUCATION AND PROPAGANDA

Fig. 1. Integrated national energy planning (INEP) and policy analysis

the whole economy. Therefore, energy planning requires analysis of the links between the energy sector and the rest of the economy. Such links include the input requirements of the energy sector such as capital, labour, raw material and environmental resources such as clean air, water or space, as well as energy outputs such as electricity, petroleum products, wood fuel and so on, and the impact on the economy of policies concerning availability, prices, and taxes, in relation to national objectives. Specific macroeconomic impacts that might be further researched include (Munasinghe 1984a):

(i) balance of payments, including trade balance, debt service, capital flows, etc.

(ii) direct macroeconomic effects, such as changes in national output and income, and factor substitution;

(iii) dynamic effects, including inflation, wage-price spirals, interest and profit rates, etc., and

(iv) long-term macroeconomic structural adjustment.

64n MM

Whilst some of these relationships -- such as foreign exchange requirements for energy imports, or investment capital requirements for the energy sector -- are at the macro level, others are more directly linked with and limited to specific user sectors. For example, policies affecting the transport sector such as subsidies to public transport, construction of highways or airports, the levels of licence fees for vehicles or excise taxes on diesel versus gasoline vehicles, tax credits for energy conservation, pollution control legislation or specific end-use planning policies may have as profound an impact on energy demands as more broad-based energy pricing, allocation or supply management policies.

65n MM

The second level of INEP treats the energy sector as a separate entity composed of subsectors such as electricity, petroleum products and so on. This permits detailed analysis of each sector with special emphasis on interaction among the different energy subsectors, substitution possibilities, and the resolution of any resulting policy conflicts such as competition between natural gas, bunker oil or coal for electricity production, diesel or gasoline use in transport, kerosene and electricity for lighting, or woodfuel and kerosene for cooking.

66n MM

The third and most disaggregate level pertains to planning within each of the energy subsectors. Thus, for example, the electricity subsector must determine its own demand forecast and long-term investment programs; the petroleum subsector, its supply sources, refinery outputs, distribution networks and likely demands for oil products; the woodfuel subsector, its consumption projections and detailed plans for rotation or reforestation, harvesting of timber, and so on.

67n MM

In practice, the three levels of INEP merge and overlap considerably. For example, a class of demand management issues that affects both macro and micro aspects of energy planning consists of those related to energy substitution or energy conservation. Within certain limits many energy resources are substitutes for one another although convenience in use and overall systems cost may vary widely. Hence appropriate supply and pricing policies may bring about significant shifts in energy demand for specific energy resources, at least in the long run.

68n MM

Similarly, individual actions or deliberate policies aimed at bringing about energy conservation -- e.g., reduction in energy usage relative to levels that would prevail in their absence -- may significantly affect energy consumption. Such conservation may simply be achieved at the expense of some loss in personal comfort or convenience (like reducing thermostat settings, driving within mandated speed limits or switching off lights in unoccupied rooms). Other means may consist of the substitution of energy by capital or labour; the replacement of pilot lights by electronic switches, the reduction in the curb weight of automobiles, recirculation of process heat in industrial plants through better engineering or lighter materials, or the installation of insulating materials in buildings.

69n MM

All the steps involved in the planning procedure, including energy supply and demand analysis and forecasting, energy balancing, policy formulation, and impact analysis, to meet short-, medium- and long-range goals, and the determination of a national energy strategy, are important topics for research.

Projections

70m (p. 22, #9) CS

The long gestation lags in energy investments and structural changes in consumption are the primary reason for making projections. Such projections should at least look forward as far as the maximum gestation lags, if not somewhat longer. For instance, fifteen- to twenty-year projections are not uncommon for electricity, and similar or longer time spans would be justified for coal.

71m (p. 22, #10) AK

It is possible to make naïve projections by extrapolating past trends; they minimize information requirements, and are not always less accurate than projections based on more sophisticated methods. But the purpose of projections is not simply to generate a set of future estimates, but also to give a better understanding of the processes involved. Hence it is advisable to use models for projection which bring in the energy-using sectors as well as the major macroeconomic constraints (Devezeaux 1984); indeed, there is not much point in projecting energy except in the context of a view of the future for the economy as a whole.

72m (p. 22, #11) JG

It is commonplace but worth stressing that a projection requires external judgment, and that it does not improve judgment but simply spells out its implications. Making a judgment about the future remains an act of imagination, however much it may be supported by information. Information relates to the past and present, and reading the tendencies that are inherent in history is one part of the skill required to make good projections. But in addition, it is necessary to forsee and incorporate into projections discontinuities between the past and the future. To cite an example of a misinterpreted discontinuity, many oil-importing developing countries coped with the 1973-74 rise in oil prices by borrowing in the short term and by increasing exports and replacing imports over the longer run. This strategy was remarkably successful, and when oil prices rose again in 1979-80, it was sought to repeat the strategy. But it could not be repeated because the circumstances had changed. The oil import ratios of the developing countries were higher in 1979 than 1973 and left less room for further import substitution, and the opportunities for further export growth were also more limited. As a result, freshly-contracted debt could not be serviced, and a number of developing countries faced insurmountable debt problems (Campbell 1983).

73n JG

The discontinuities arising from oil prices were beyond the control of the developing countries that were affected by it. But there are also controllable discontinuities. In modelling language, there is a distinction between exogenous and instrumental variables; and if projections on exogenous variables point to unviable or unacceptable futures, discontinuities have to be introduced into instrumental variables to lead to a more desirable future. The manipulation of instrumental variables to lead to better future outcomes is the essence of planning. However, the pace of change depends on the magnitude of the discontinuities introduced, on which there is often debate amongst the planners. In the Soviet Union after the revolution, a debate arose between "geneticists" who argued that plan goals should be constrained by the trends inherent in the historical conditions, and "teleologists" who maintained that the goal of planning was to change these inherent tendencies themselves (Carr and Davies 1969). A similar debate underlies the recent global energy projections, a number of which are summarized in Appendix 2. The world faces an unacceptable future in the form of declining oil supply and rising levels of atmospheric carbon dioxide. Some

futurologists have looked for the minimum changes in the current lifestyles and power relations required to make the future endurable, whilst others have pointed towards more fundamental changes (Goldemberg et al. 1985). Projections at the national level would similarly open up debate on desirable futures, and debate on these is essential for rational and widely acceptable choices to emerge.

Energy management and tools for policy implementation

74n MM

Integrated national energy planning (INEP) should result in the development of a flexible and constantly updated energy strategy which can meet the national goals discussed earlier. Such a national energy strategy may be implemented through a set of energy supply and demand management policies and programmes.

75n MM

To achieve the desired national goals the policy instruments available to Third World governments for optimal energy management include: (a) physical controls; (b) technical methods; (c) direct investments or investment-influencing policies; (d) education and promotion; and (e) pricing, taxes, subsidies and other financial incentives. Since these tools are interrelated, their use should be closely coordinated for maximum effect.

76n MM

Physical controls are most useful in the short run when there are unforeseen shortages of energy. All methods of limiting consumption by physical means such as load shedding, rotating power cuts in the electricity subsector, reducing or rationing the supply of gasoline or banning the use of motor cars during specified periods, are included in this category. However, physical controls can also be used as long-run policy tools.

77n MM

Technical means used to manage the supply of energy include the determination of the most efficient means of producing a given form of energy, choice of the least-cost or cheapest mix of fuels, research and development of substitute fuels such as oil from shale, coal or natural gas, the substitution of alcohol for gasoline, and so on. Technology may be used also to influence energy demand, for example, by promoting the introduction of more efficient energy conservation devices such as more fuel-efficient automobiles, better stoves for woodfuel, and by research into and promotion of solar heating devices, etc.

78n MM

Investment policies have a major effect on both energy supply and consumption patterns in the long run. The extension of natural gas distribution networks, the building of new power plants based on more readily available fuels such as coal, or the development of public urban transport networks are just some of these policies. It should be noted that many of them may well be undertaken by sectors other than energy -- examples are investments in transportation facilities or the systematic installation and/or electrification of deep-well irrigation pumps -- close cooperation between the energy administration and planning authorities of these other sectors is obviously called for.

79n MM

The policy tool of **education and promotion** can help to improve the energy supply situation through efforts to make citizens aware of cost-effective ways to reduce energy consumption, of the energy use implications of specific appliances or vehicles, and of the potential for substitution of energy by capital (e.g., proper insulation).

80n MM

Taxation and subsidies are useful policy instruments that can also profoundly affect energy consumption patterns in the long run. For example, countries which have imposed high taxes on gasoline have generally had significant results in terms of reduced automobile use, more efficient vehicle fleets, and so on. Subsidies have similarly encouraged energy-saving capital investments.

81n MM

Pricing is politically sensitive, but a most effective means of demand management, especially in the medium and the long run (Munasinghe and Warford 1982). However, pricing has limitations and must be skilfully combined with other nonprice policy instruments for best results. For example, in the traditional fuels sector (e.g., fuelwood), where there is no well-developed market, pricing policy may not be effective. Reduction of fuelwood use may require other nonprice measures such as disseminating a more effective domestic cooking stove. In the case of very high-income consumers, who are willing to pay an extremely high price for their comfort (e.g., air conditioning), high prices might not reduce demand significantly; but they could be used instead as a revenue-generating mechanism. At the other end of the scale, raising prices to low-income energy consumers may simply cause them to spend a greater share of their income for energy purchases without affecting energy use, because these consumers are already at the "basic needs" level and could not do without a minimum amount of energy (e.g., kerosene for lighting in rural homes). In such cases energy pricing policy would cause hardship by limiting the income available to poor households to purchase essential nonenergy items.

82m (p. 25, #16) CS MM

We have been struck by the ubiquity of average cost pricing based on historical costs, as well as substantial taxes on and subsidies to, energy industries in developing countries. Average cost pricing has probably distorted competition at the margin between different sources of energy, and made it more difficult for new sources to penetrate the market. Without contesting the advantages of the market mechanism, we consider it obvious that the existence of monopolies, often state-owned have led to market failures. We see the need for greater reliance on prices based on the future resource costs of energy supply rather than on historical costs. Such a forward-looking approach establishes a pricing benchmark which may be further modified in the light of other socioeconomic criteria. Such pricing policies would be based on very different principles from the currently prevalent set of taxes and subsidies introduced to improve income distribution (for instance, taxes on gasoline for cars, which are mostly owned by the well-to-do, and subsidies on kerosene, which is used as an illuminant by the poor). Such distribution-related taxes and subsidies are not confined to energy, but are much more general, and introduce arbitrariness and inflexibility in the price system. Unequal income distributions and weak welfare services create political pressures in developing countries which reduce the efficacy of the price system as a mechanism for the application of resources. We are in favour of general income subsidies and public welfare services in developing countries in order that the price mechanisms may be brought more actively in play as a policy instrument.

83o (p. 25, #17)

Second, most developing countries deploy profit taxes on enterprises which, combined with write-offs on capital expenditure, can create powerful incentives for new investment; these are reinforced in some countries by subsidies on interest or privileged access to investible funds. There is an argument for a shift in the taxation base from profits to costs. But failing that there is a case for countervailing the incentives given to energy-using equipment bv corresponding incentives to energy saving, whether with or without investment.

84n MM

In summary, controlling the use of energy through coordinated use of the various policy tools is the principal goal of energy supply and demand management. Practical aspects of such policy coordination are discussed later.

Constraints on policy:

85n

The chief constraints that limit effective policy formulation and implementation are: (i) poor institutional framework; (ii) insufficient manpower and other resources; (iii) weak analytical tools; (iv) inadequate policy instruments; and (v) other constraints.

86n MM

(i) **Institutional framework:** An adequate institutional framework for energy policy formulation and implementation should have at least three well-defined and balanced elements: policy-making, implementation, and research and development. Most often, all three aspects are mixed together, to the detriment of all. For example, senior energy decision-makers, who should be devoting a significant part of their time to major policy issues, are invariably embroiled in day-to-day crisis management. The academic and research communities frequently focus their interest on energy problems that are not significant from the national policy viewpoint or are irrelevant (Munasinghe 1984b). Finally, even when separate organizations exist for policy, operations and R&D, their efforts are uncoordinated. Studies of institutional frameworks that have been successful should be of considerable value to many developing countries, seeking to restructure their energy organizations. Usually, the existing line agencies, such as electric utilities and oil companies, are well able to attend to daily operational needs, whilst institutions like universities and research centres exist for longer-term R&D. The weakest area that needs considerable strengthening is the policy analysis and formulation aspect, especially since the heart of INEP lies here.

87n MM

(ii) **Manpower and other resources:** The lack of skilled manpower for policy analysis and development as well as energy management and project implementation, is a severe handicap. Education and training programmes have a vital role. Furthermore, specialists with broad skills in energy planning and policymaking are likely to be more scarce, and therefore more valuable, than those having expertise in narrower areas such as electricity generation or refinery operations. Teams devoted to multidisciplinary analysis of energy problems (e.g., including technologists, economists, financial analysts, and other social scientists), should be built up. Adequate remuneration, job satisfaction, and funding for research and the associated infrastructural facilities must be provided to ensure that those trained in these new skills -- usually at great cost -- are available to the government for reasonable periods of time, and not subject to brain drain.

88n MM

(iii) **Analytical tools:** As mentioned earlier, work done during the last decade has led to the conclusion that a hierarchical modelling framework employing microcomputers might be well suited to more effective policy analysis and application (Munasinghe 1985). Such a set of models developed and used recently in Sri Lanka are described in Appendix 3.

89n MM

It is important to note that all computerized activities should be first tested and validated manually, at a relatively simple level, and that it is only later, as data and local analytical skills improve, that the transition to more sophisticated computer modelling may take place. Furthermore, whilst the computer models are being developed over a period of time, critical energy policy options could be examined by hand, and appropriate decisions taken and implemented (e.g., regarding energy pricing, demand management and conservation, as well as choice of renewable supply technologies). The analytical framework should reflect the real world as closely as possible, especially developing-country constraints. It should have a policy focus, so that the kinds of questions typically posed by senior decision-makers might be easily formulated and modelled.

90n MM

(iv) **Policy implementation tools:** The constraints and research issues concerning policy implementation tools have been discussed earlier in this chapter.

91n MM

(v) **Other constraints:** In the context of developing countries we generally face additional constraints on energy policies. There may be severe market distortions due to taxes, import duties, subsidies, or externalities which cause market (or financial) prices to diverge substantially from the true economic opportunity costs, or shadow prices. Therefore, on the grounds of economic efficiency alone we may

have to make (second-best) shadow pricing adjustments. However, these again may have to be modified in anticipation of energy user reactions that will be based on market prices rather than underlying economic cost considerations. Furthermore, there often are severe income disparities and social considerations which call for subsidized energy prices or rationing to meet the basic energy needs of poor consumers. Finally, there are usually many additional considerations that affect policy requirements, financial viability and autonomy of the energy sector, regional development needs, as well as sociopolitical, legal and other constraints.

Policy research

92m (p. 27, #20) CS

If a policy framework consisting of the three above elements is created, it will generate substantial research requirements. Policy research is not uncommon in developing countries. Whilst it was prevalent in a number of them even earlier, many recognized its need in the wake of the serious energy problems that arose in the seventies. Many others were forced to produce plans before international funding agencies in order to justify investment projects for funding. And international research funding agencies also looked kindly on policy research as a relatively low-cost way of getting involved with policy-makers. Thus policy research has not suffered from neglect. However, its quality could be improved; and quality improvement calls for organizational changes.

93e (p. 27, #21) CS AR JG DS

If properly articulated, a policy framework should have a considerable effect on research. Yet our reviewers have found that the connexion between national priorities and the activities of research centres is tenuous if not absent (Bhushan 1984; Torres 1984). Most research in developing countries is funded by the state. When the government wants inputs to policy, it invariably does so in a hurry, and it does not get them with the speed it wants from independent research institutions. (The trade-off between speed and quality is often different for researchers and policymakers). Many governments also like to have an influence on the views of research institutions. Hence they have tended to disfavour independent research centres, and either to set up captive research institutes or to hire consultants. Both are more responsive to immediate demands, but the quality of their research suffers.

94o (p. 27, #22)

The faster the results are required, the less time there is for fresh research, and the greater the reliance on inherited knowledge. Unfortunately, neither consultants nor official research organs are well organized for accumulating knowledge in depth. Both tend to move quickly across widely-separated areas as required to skim the available information; neither systematically stores knowledge in libraries, databases or people. The result is repetitive and derivative work; in socioeconomic research, repetition generally means regurgitation of conventional wisdom.

95o (p. 28, #23)

The first need of competent policy research in developing countries is independent, professional research institutions that can act as a repository of knowledge. That the present-day independent institutions do not serve the needs of policy is an organizational and political failing which can be corrected. Amongst the corrective measures required, the following are the more basic ones.

96o (p. 28, #24)

First, government funding should not be channelled primarily into captive research institutions; and among funded research institutions it should not unconditionally cover all forms of expenditure. It should go into the funding of the infrastructure of research institutions, especially those parts of it which are crucial to the quality of research, such as the library, instrumentation, experimental facilities and computation facilties. The funding of manpower should

go to the support of specialists available for policy research as first priority: such specialists and their projects should be attached to large, well-endowed research institutions. The salaries and other terms should be uniform enough to encourage active interflow between policy-makers, researchers working on policy and other researchers.

97o (p. 28, #25)

Second, it is important that the government should become an informed buyer of research. This involves that the persons responsible for buying and judging research in the government should be trained and experienced: they should in fact be interchangeable with the persons who produce research for them, and should interchange positions with them from time to time. Governments often draw upon experienced people from enterprises and research institutions, but the reverse flow is equally important if policy-makers are to be competent judges of research. Policy-making is responsible and often technical work, and many governments in developing countries try to ensure the supply of high-quality manpower for it by setting up speciallv privileged administrative cadres or hiring expensive consultants from outside. But it is not enough to ensure a high intelligence quotient in the government; it is also necessary to feed the intelligence with knowledge to be acquired outside the government from time to time.

98m (p. 29, #26) MM

Third, socioeconomic research provides fruitful ground for policy research even if it is not directly relevant or if it is unsympathetic to government policy. The costs of collecting socioeconomic information on a large scale can be very high, and unless the government subsidizes it, integrated macro-level research is likely to suffer as it does in many developing countries. The government can stimulate socioeconomic research both by collecting and publishing statistical and other information, as from censuses, and by financing the collection and publication of such information by research institutions.

99m (p. 29, #27) AK CS MM

We should at this point address the question of policy research and dissent. Research that is a direct input to policy is only a part of socioeconomic research; such research also arises as a result of the routine activities of researchers as well as of a critique of policies. In societies with mechanisms for peaceful changes in policy-makers or in policies, critique tests the robustness of policies and expands the range of policy alternatives available. Where change is not institutionalized, however, policy critique is often looked upon as a threat to authority and suppressed. Since we are in favour of systematic and peaceful change in our societies, we need hardly say that our sympathies are not with brittle, unrepresentative regimes. The capacity to advance knowledge and to use it in policy is a resource that is forfeited by intellectually intolerant governments.

Freedom of manoeuvre

100n AK ZYJ

Broadly speaking, the larger a countrv, the less its dependence on the outside world, and the greater its freedom of manoeuvre in policv-making. Further, the economic benefits of research depend on its scale of application; this is a major reason why research tends to be concentrated in large countries. The large majority of developing countries is, however, small. If thev are to acquire greater freedom to formulate policy, they should have closer association with research done by their larger neighbours, and they would need to coordinate policies amongst themselves. If they are to acquire greater capacity to do and to use research, they would need to share the costs, facilities and benefits of research. As it happens, almost all developing countries are concentrated in Africa, Asia and Latin America; most of their neighbours are other developing countries, and regional cooperation amongst them also implies south-south cooperation.

2. Producers

101m

Producers are the practitioners and the major repository of production technology. However, all producers of goods and services are not producers of new or improved technology. Intensive technological investigations tend to be centred in research and teaching institutions. Within industries, technological innovation tends to concentrate in industries where the same or similar processes are capable of making a wide range of products, namely engineering, electricals and electronics and biotechnology.

102o (p. 30, #2)

The absence or relatively small size of these innovative industries in developing countries is one reason for their relatively unimportant role in innovations. But it is not the only one: there are other and, in our view, more remediable reasons. We discuss the possibilities of action in three spheres: R&D, technological capacity and the technological infrastructure.

Research and development

103o (p. 30, #3)

It is customary to lament the tendency of producers in developing countries to rely on imported technology and not to develop their own (Cooper 1973; Stewart 1977). In the field of energy we have encountered some outstanding instances of R&D-led innovation, such as alcohol-powered cars and charcoal smelting of iron in Brazil (Torres 1984). But by and large, both the extent and the effectiveness of R&D in developing countries leave room for improvement.

104m (p. 30, #4) CS

Research and development as commonly understood has two components. The first involves trying out processes on a small scale, or prototypes produced singly or in batch, with the objective of minimizing costs and reducing the risks of large-scale development. Applied research is well understood and is common in developing countries; in fact, it may be argued that there is too much of it and too little of development. There is a suggestion of this in the breakdown of the 365 NRSE research projects in new and renewable sources of energy in Latin America enumerated by the Inter-American Development Bank and the Institute for the Integration of Latin America in 1981. Only 7 per cent of them were directed towards "mass development", i.e., commercialization, and only 28 per cent were large projects which may eventually have substantial energy substitution impacts. However, many were in areas where it was too early to commercialize the results of research.

105o (p. 31, #5)

All -- perhaps most -- of the projects in Table 1 are not ones being executed by producers; one of the reasons for the imbalance between applied research and commercialization in developing countries is that public funds are more liberally available to research institutes which are not attached to producers, and many of which are state-owned. Producers are given tax incentives for spending on R&D, but their R&D is seldom directly funded. The reasons given are various: for instance, that producers' R&D would contribute to their profits, so they should fund it; the results of the R&D would not become generally available; producers are under private ownership, etc.

106o (p. 31, #6)

The policies in developed market economies are different; in many, public funds are actively allocated to R&D in private firms. The reason is that the competitive advantage thereby gained by private firms is seen to be a national advantage in international competition. Further, governments can influence the

TABLE 1

Distribution of 365 research projects on new and renewable sources of energy in Latin America, 1981

(per cent)

	Argentina	Brazil	Colombia	Costa Rica	Mexico	Uruguay	Total
Type of research							
Basic research	22	14	27	23	25	45	26
R&D	66	81	61	73	68	55	67
Mass development	12	5	12	4	7	0	7
	100	100	100	100	100	100	100
Type of technology							
Simple, small, low-impact	55	21	58	35	46	41	41
Complex, intermediate, high-impact	32	44	4	27	27	4	31
Complex, large-scale, high-impact	12	35	38	38	27	55	28
	99	100	100	100	100	100	100

Source: Inter-American Development Bank/Institute for the Integration of Latin America (1981).

direction of research if they fund it directly, but not if they release funds for it through tax incentives. The governments in the USA, France and Japan have been particularly effective in influencing the course of technological development to some of their energy industries.

107e (p. 31, #7) CS DF JG

Thus the use of public funds to fund the complete chain of R&D in producer firms is an instrument that developing countries could use more purposively to generate new technologies that are appropriate to their own circumstances. Such a strategy may not work where the producer firms are multinational ones: they may ignore national research needs, and concentrate research and development in their mother countries. The emergence of national producer firms is a prerequisite of a national R&D strategy.

108o (p. 33, #8)

Development is not just a matter of funding, however, but requires special managerial skills. It involves the setting up of large plants in the case of process industries, and mass production facilities in the case of product industries. The plants almost always require large external inputs, and the task of the development manager consists of coordinating the inputs so as to set up plants cheaply for high-quality production. This coordination requires the combination of technological and commercial expertise -- expertise of the informed buyer. This is why it is impossible to separate development from the producer.

109m P. 33, #9) MM

Thus the stress needs to shift from R&D projects to building up the capacitv of producers in developing countries to carry out R&D or to develop, commercialize and disseminate products based on the research of others (Munasinghe 1984b).

Technological capacity

110o (p. 33, #10)

R&D is a statistical category created in the search for the sources of innovation. However, whether a producer innovates or not, does not invariably depend on whether he has an R&D department, or how much he spends on it. What matters is whether he observes and reacts to his business environment in technological terms. The more rapid the rate of technological change, and the smaller the firm, the more important this monitoring function becomes:

111m (p. 33, #11)

"The apparently random, accidental and arbitrary character of the innovative process arises from the extreme complexity of the interfaces between advancing science, technology and a changing market. The firms which attempt to operate at these interfaces are as much the victims of the process as its conscious manipulators. ... These considerations lead to three conclusions of fundamental importance. First, since the advance of scientific research is constantlv throwing up new discoveries and opening up new technical possibilities, a firm which is able to monitor this advancing frontier by one means or another may be one of the first to realise a new possibility. Strong in-house R&D may enable it to convert this knowledge into a competitive advantage. Second, a firm which is closely in touch with the requirements of its customers may recognize potential markets for such novel ideas or identify sources of consumer dissatisfaction, which lead to the design of new or improved products or processes. In either case, of course, they may be overtaken by faster-moving or more efficient competitors or by an unexpected twist of events, whether in the technology or in the market. Third, the test of successful entrepreneurship and good management is the capacity to link together these technical and market possibilities, by combining the two flows of information." (Freeman 1982: 111).

112o (p. 34, #12)
The benefits of monitoring the environment and translating it into product and process changes are evident even if a firm is substantially dependent on outside sources for its technology. Thus technologically sophisticated observation is within the capacity of many firms in developing countries, and deserves to be encouraged both directly and indirectly -- for instance, through cooperative industrial monitoring centres, consultants, libraries, etc.

113o (p. 34, #13)
One of the aspects of this trained observation is learning from the market. Technological interaction between buyers and sellers is an important source of innovation in industrial countries; it is a strong feature of technological development in oil, coal and power industries, for instance. Thus it is useful to build up the capacity to learn from experience not only in the equipment-manufacturing industries but also in the oil producers, coal-mining enterprises and power plants of developing countries.

External conditions

114o (p. 35, #14)
In the preceding two sections we have stressed R&D and technological capability as two aspects of technological adjustment to the economic environment. Of these, the development of technological capability is open to a much larger proportion of producers; and both for them and for those who do R&D, external sources of ideas are very important in the process of innovation: more important than their own contribution, in fact (Pavitt 1984). The link between innovation and the information that went into it is, however, not direct or predictable; instead, key information is often provided through unrelated research. Thus research outside the business sector can strongly contribute to innovation (as we discuss in the next section), but frequent interaction between technologists in industry and those engaged in scientific research is essential. This interaction is much facilitated by previous student-teacher or collegial relationships between the two groups, and is much more frequent and effective if it is verbal. Both the availability of scientists outside firms for consultation and their direct participation have been found to contribute to innovation (Price and Bass 1969).

115o (p. 35, #15)
Major innovations are few and far between; much more often, a line of technological improvement is perceived and exploited over long periods. This is how the efficiency of thermal power plants has been raised by progressively increasing steam temperature and pressure, the capacity of draglines has been raised in coal mines, or the efficiency of photovoltaic cells has been improved. In this type of incremental change, example and emulation are important, and emulation is more likely if a producer has technologically sophisticated competitors to observe. The considerable discussion on the effect of market structure and technological change is not conclusive (Kamien and Schwartz 1982). But what matters is not the precise market structure, but whether producers have technologically sophisticated competitors to reckon with.

116o (p. 36, #16)
Taking a look across developing countries, we can hardly say that one type of ownership is superior to another: there is a great variety of ownership patterns, and variations in performance seem to be as great within each ownership type as between them. But ownership undoubtedly affects technological capacity through the autonomy of the management, its technological sophistication, its openness to information from outside, and the flexibility of organization which is required to make quick organization changes within the firm.

Small producers

117o (p. 36, #17)
The foregoing refers to large industrial producers who can afford substantial technological manpower and technological resources on their own. Far more numerous are small producers, for whom research is full of risk:

> "When you are buying a lottery ticket or playing roulette you know that on the average you are losing. In research the situation is different: it is obvious that on the average worldwide research had led and is leading to considerable profits. Every research project is a bit of a gamble, but it is a gamble with very favourably loaded dice. Also, you always get some return; even if your original goal is not reached you will have found some useful things. All the same, although you may expect that on the average R&D will be profitable, there are fluctuations. In a big firm you can afford large fluctuations, in a small firm you must be more careful: survival may depend on one single project." (Casimir 1983: 179).

118o (p. 36, #19)
The norm in many sectors in developing countries is, however, a multiplicity of producers who are too small even to contemplate research. But it is important that they should use the results of research. In energy, for instance, at least three sets of research programmes -- those on charcoal, woodstoves and woodlots -- are aimed at small producers. It is necessary to ask ourselves what are the conditions of success in improving the technology for use by numerous small producers with low technology capability.
119n AR CS
First, few innovations are confined to a single stage in the production process. Product innovations generally require process changes, and changes in one part of a process require consequently changes in other parts. In a large company that internalizes the entire chain of innovation, these structural adjustments are brought about by the interaction between different departments of the company, for instance the R&D section, the engineering department, the procurement department and other line departments. In fact, the ability of a large company to innovate depends crucially on the degree of coordination between those sections of it that generate ideas and those that embody them into production. Where the producers are small, these two functions are necessarily separated: ideas must come from outside research institutes, and must be implemented by the producers. This makes the coordination of the two more difficult, but no less necessary. It is essential that the researchers should be in close touch with some producers, right from the outset, and so should have feedback from potential users of research. The lack of intimate contact between the two often leads to the premature transfer of innovations before they are ready for commercial development, and hence to failure.
120n AR CS
Second, the internalization of the entire chain of innovation in a large enterprise ensures that the benefits of innovation accrue to it as long as imitators do not cut into its market: there is a direct link between the investment in innovation and the benefits from it. Where the producers are small, this chain is broken; the costs of innovation are incurred by a research institution whilst the benefits accrue to the producers. The research institution may try to appropriate a part of the returns from the innovation through royalties. But the volume of the returns that can be appropriated depends how long the producers to whom the innovation is transferred can retain its exclusive use. Innovations are generally copied so rapidly by small-scale producers that it is difficult to restrict their use to a few. Even if it is possible, rapid diffusion and equal access for all producers may be held to be in public interest.

121n AR CS

Third, the introduction of innovations is often risky, and the risk-taking capacity of small producers is limited, and the cost of failure is greater for them because of their undercapitalization and the keen competition they face. Hence the transfer of innovation to small producers must be accompanied by a mechanism for eliminating or reducing the attendant risks. Innovations for small producers have to be proved and debugged to a greater extent than for large ones, and may even then need to be supported by risk-avoiding or risk-sharing mechanisms.

122n AR CS

Finally, insofar as the introduction of an innovation requires capital or technical skills, the access to it will vary among small producers according to their command of these two factors. In general, the strong and technologically more capable producers are more capable of taking up innovations. Thus the benefits of innovations tend to be distributed unequally, and to increase the unequal distribution of resources among small producers.

123n AR CS

Thus research for small producers faces peculiar problems. Policy-makers in a number of developing -- and even some industrial -- countries are aware of these problems, and have tried to solve them in various ways. A comparative review of their experiments would be of considerable practical value.

3. Research Institutions

124m (p. 38, #1) CS

We earlier said that the technological capacity of producers lay in making technological responses to their socioeconomic environment. Research and training institutions are the repositories of accumulated knowledge and of the skills necessary for advances in it. The problems for them to tackle must arise from the conditions in their countries and societies, and the solutions they look for must arise from their accumulated knowledge and experience. They must be in touch with government and industry for utilization of their research. They should serve a number of functions:

125e (p. 38, #2)

(a) **Accumulation of experience:** The quality of research depends considerably on researchers' accumulated experience. The experience accumulates from sustained application to meticulous research, which requires good facilities. Governments and producers have a relatively use-oriented and short-term approach to knowledge, and are poorly suited for accumulation of experience. Research institutions serve as reservoirs of expertise on which other users can draw. A minimum concentration of expertise is required if it is to serve as a critical mass.

126n

(b) **Diffusion of intellectual skills:** The amount of work a researcher can do in his lifetime is limited. For advances in knowledge it is essential that researchers should work together, that they should improve their skills and pass them on to succeeding generations of researchers, and that they should educate those who are not engaged in research. Research and training institutions should provide the mechanism for the transfer of intellectual skills.

127m (p. 38, #3)

(c) **Efficient use of intellectual assets:** The knowledge residing in research institutions is public and widely accessible; their location there should be designed to the broader and fuller utilization of their assets -- libraries, classrooms, instrumentation, etc.

128o (p. 38, #4)
(d) **Juxtaposition of diverse disciplines:** Radical insights often come from the coupling of ideas from unrelated disciplines. Many practical problems require the bringing together of very diverse fields of knowledge. Broad-based research institutions should serve as the places where unrelated disciplines come together.

Research funding

129o (p. 39, #5)
What distinguishes or should distinguish research institutions from research facilities in business and government is the greater breadth and depth of knowledge they bring to bear on the problem, and the breadth and depth must be based on superior research facilities -- libraries, laboratories, computation facilities, etc. These are precisely the assets which result-oriented project funding discriminates against. Funding agencies, national and international, endeavour to buy research at its marginal cost, which consists mainly of personnel costs. The result is levels of manpower that are not supported by the infrastructure, and the quality of research suffers. Project funding also orients researchers towards doing a series of unrelated, short-term research projects, and prevents them from developing depth.

130o (p. 39, #6)
The utilitarian approach also leads to institutions that are too narrowly specialized. Priority areas of research keep changing, whilst institutions have a natural urge to perpetuate themselves. If funds are given to old institutions with unfashionable specialization for new subject areas, the funds may be in danger of being diverted to the old areas. Hence the tendency is to start new institutions for new subject areas. Disciplines, however, do not follow social priorities, but are always being redefined for efficiency in research. There are limits to the amount of work a researcher can do in his lifetime; growing subjects keep dividing and redividing so that each remains researchable by a small number of researchers who can communicate with, check on and learn from one another (Menard 1971: 40-57). Thus proliferation of institutions congealed in specializations that are defined in utilitarian terms leads to poor research and low productivity.

131m (p. 39, #8) JG
The need to make a long-term investment in knowledge and to make research respond to the changing needs of society are twin objectives that are difficult to combine. Many solutions have been tried out across the world, and none that we know is ideal. Lip-service has often been paid to programme funding. But funding agencies in democratic countries have to answer questions from their governments and their fellow-citizens about the utility of their activities and need to be able to judge and demonstrate results within reasonable time periods. They prefer project funding because they can monitor and control short-term projects more easily than programmes. If they are to be persuaded to fund programmes, programme funding also needs to be combined with a method of evaluation.

132o (p. 40, #8)
The foregoing considerations point, in our view, towards a funding system with the following elements.

133n
(i) **Growth by accretion:** Large, multidisciplinary institutions have the advantages of shared facilities, greater possibilities of interaction amongst researchers, and consequently of greater breadth in research. At the same time, institutions must change in response to changing directions of demand. The solution to this problem is not to proliferate small, new research institutions but to let old ones grow by accretion of programmes designed to meet new demands.

134o (p. 40, #10)
(ii) **Programme funds as an investment:** The institutions should be given long-term funds to cover all requirements, material and human, of new areas required. New programmes should be set up only if adequate backup in terms of material facilities is available for quality research.

135o (p. 40, #11)
(iii) **Projects for return on the investment:** Projects should not be looked at as a method of funding research but as a way of putting investment in the form of programme funds to use. When new programmes are considered, the volume of projects they may attract should be assessed. Choice amongst and allocation between programmes may be based on the volume of projects they may be expected to generate.

136o (p. 40, #12)
(iv) **Decentralized direction of programmes:** If programmes are to succeed, autonomy and continuity of their direction are paramount. Research institutions should be run as cooperatives of programmes. At the same time, active management of programmes is essential to drive them forward towards efficient implementation of projects.

137n AK
(v) **Centralized planning and resource allocation:** The short-term allocation of researchers and other mobile resources would follow the project requirements. But if researchers are to be utilized fully, and if their careers are to mould them into skilled and experienced resource persons, successive programmes must be selected so that experience is acquired in useful directions. Further, research takes time, whilst its users want results quickly. This gap between what is needed and what is possible can be partially bridged by anticipation, and research programmes can be launched in advance of projected demand for them. The forward vision and the management of resources that this building up of experience and knowledge require are the tasks of the institutional management.

Directing research

138o (p. 42, #19)
In our view, the unit of research management should be a programme. A programme should be funded for a fairly long period -- five to ten years -- and should then be either continued or expanded on the basis of the projects it attacts or disbanded. It should be the instrument of converting the investment made in it into project output. If it is to serve this function, a programme must have considerable autonomy in the way it spends its budget, recruits its personnel, seeks projects and carries them out. Hence we envisage that most administrative functions and power should be in the hands of programme directors; they should have both autonomy and control.

139o (p. 42, #20)
The position of programme directors would be one of great responsibility. They would be responsible on the one hand for dividing up assignments into research tasks that can be tackled by individual researchers or teams, and on the other for coordinating their output and putting it in a form that can be useful to the client. Hence programme directors will need both technical and managerial expertise, and would everywhere be a rare breed which must be nurtured carefully.

140o (p. 42, #21)
If programme direction functions well, the overall direction of research institutions will be relieved of most of day-to-day management. Their task will essentially consist of the management of common resources -- including funds for allocation between programmes, which may come either from external programme grants or internal earnings from projects -- and forward planning.

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Research and training

141m (p. 41, #13) CS

Research and training differ from each other in a number of significant ways:

(i) The object of research is to produce high-quality inputs for users; the object of training is to improve the intellectual capability of students. Research has a training effect and training has a research component. If research is used for training, there is a danger that the results would be poor and wasteful; if on the other hand, students are used in research, they may be given hack work with a negligible training element.

(ii) The time spans involved are different. In order to ensure and monitor the students' progress, training is generally broken up into short, uniform periods. The time span of research is more flexible and generally longer.

(iii) Although this is not an absolute difference, the focus in teaching is on the individual student and the individual teacher; in research it is generally essential to form teams and to coordinate the work of individuals. To be useful in teaching, problems have to be small enough to be tackled by a single student in a fairly short time period. No such restrictions can be placed on actual research assignments; in research, it is the size of the team that has to be tailored to the problem.

142m (p. 41, #17) CS

In these ways, research and teaching will both suffer if they are too closely integrated. But separation is also undesirable; both are complementary. They require similar material facilities. Research can lead to the restructuring of teaching in more relevant directions; conversely, teaching can lead a researcher to question and test his ideas. Hence it is desirable that research and teaching should be done in sister institutions which share facilities and interchange personnel.

Research communication and informatics

143n CS MM

Research is intended to add to knowledge, but it can also rediscover knowledge. Whether it adds new knowledge depends on how well-informed researchers are on the current state of knowledge. Whilst one of the purposes of education and training has been to give all researchers a minimum initial stock of knowledge, the degree of knowledge has historically varied considerably between researchers in the same field; access to comprehensive libraries and to experienced colleagues has been highly unequal between research institutions, and those in developing countries have suffered in this respect. The poor state of communications in developed countries has contributed to the inequality of access.

144n CS MM

Recent technological advances in informatics have, however, created the possibility of greatly reducing this inequality. Computer-based techniques of information storage and retrieval are being applied to libraries. The currently available systems are either small and limited in capacity or large, custom-made and expensive. One reason why cheaper and more standardized systems have not emerged is that major libraries in industrial countries are old and large, the costs of conversion of their cataloguing systems are high, and their manual cataloguing

systems impose special requirements on their computerized successors. These constraints are less applicable to the newer and smaller libraries that are common in developing countries. It is in their interest to promote the development of, and to adopt, computer-based cataloguing systems of greater versatility and use to researchers.

145n CS MM

The same informatics and computer-based technologies are also making the transfer of information easier and cheaper. The use of satellites has brought down the capital costs of communication networks considerably, and the information that can be transmitted can be aural, visual or coded (e.g., written). The extension of these cheap and convenient communications to developing countries must await the renovation of their existing telecommunication networks and the installation of terminal facilities. But the enormous potential benefits of better communications to research, in the form of improvement in its quality and the prevention of duplication, are obvious.

146n CS MM

Prevention of duplication is of even greater interest to research users and to funding agencies than to researchers, for better acquaintance with the state of knowledge can save wasteful expenditure on repetitive research. Hence research users and funding agencies should look upon expenditure on libraries, communications and research networks as ways of increasing the effectiveness of their total expenditure on research.

4. International Funding Agencies

147o (p. 47, #1)

Paradoxically, this is the only group on whose activities we have statistical information; it throws an interesting light on their activities.

Investment

148m (p. 47, #2) CS

Agencies fund two types of activities: investment and research. We estimate the total concessional and nonconcessional loans for energy investment from developing market economies to to developing countries in 1975-1981 at US $92 billion, of which multilateral loans were US $17 billion, bilateral concessional loans were about $10 billion, commercial bank loans were about $30 billion and the remaining $35 billion consisted of nonconcessional suppliers' credits (estimated from World Bank (1983a)). Except for equipment being manufactured in a few of the larger developing countries, principally China, India, Brazil, Mexico and the Republic of Korea, almost all energy-producing and transforming equipment was imported by developing countries, and almost all that was imported was financed to a substantial extent by loans and export credits. Thus loans of one kind or another financed a high proportion for energy investment in many developing countries.

149o (p. 47, #3)

More detailed estimates are available from two sources and are summarized in Table 2; both are deficient. For 1975-1981 we do not have a breakdown of bilateral official loans, whilst for 1980-82 the figures of export credits include only

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officially guaranteed credits with a term over 5 years: officially guaranteed credits under 5 years, estimated to be about half as much as those over 5 years, and credits without an official guarantee, for which no figure is available, are excluded.

150m P. 51, #4) MM JG CS

The striking feature of these figures is that almost all multilateral loans go to energy production (as against energy saving); and a high proportion of them goes to electricity. Their share in loans is also higher for electricity than for other industries. The power industry has certain characteristics that make it attractive to funding agencies. Its plants are neatly packaged, and their capital costs are easy to predict. Its technology is standardized, and it is more difficult (though not impossible) to mismanage. In most developing countries, demand for power has been growing rapidly, so a power plant is less likely to suffer from lack of demand. And finally, power plants are simply connected to grids; power needs no special marketing effort as long as demand for it is growing. However, these features would make loans to the power industry attractive to all funding agencies, and not simply the multilateral institutions. Developing countries prefer to borrow from multilateral institutions because of the somewhat lower interest and appreciably longer terms they offer, and as preferred lenders they take the pick of power loans.

151o (p. 51, #5)

On the other hand, because of their favourable lending terms the multilateral institutions are not popular with competing funding agencies, whether they are national official agencies or private banks; and the political pressure of these competitors keeps the multilateral institutions out of the markets in which their competitors are specially interested.

152m (p. 51, #6) CS

The international conventional power plant market is extremely oligopolistic and not keenly competitive. Seventy per cent of the world power equipment exports come from 14 firms in five industrial countries -- USA, Federal Republic of Germany, Japan, France and the UK. The firms build up spheres of influence in developing countries through subsidiaries; there is even less competition within each market than internationally (Surrev and Chesshire 1984). In the circumstances, it is less necessary than in more competitive markets for an industrial country to push the exports of its national firms, which are more or less satisfied by the even-handed funding of projects by multilateral institutions.

153n CS

Market concentration is even greater in nuclear power plants. Of the 194 reactors built in market economies till 1984, 132 were supplied by four firms -- two from the USA, one from France and one from Canada, all countries with large indigenous nuclear power programmes (Desai 1984). The East European market is served by the USSR, which itself has a large nuclear capacitv (Chung 1985). The influence of host-country governments on the export of equipment and technology is much greater in the case of nuclear plant than of conventional electrical plant, because of its implications for nuclear proliferation. The resulting difficulty of obtaining technology has led a number of developing countries, including Argentina and India, to develop their own capabilities in nuclear power plant construction.

154o (p. 52, #7)

The oil and gas equipment markets are more competitive, but in most types of oil equipment, US firms predominate. In recent years, however, oil development in the North Sea, Southeast Asia and China has led to the emergence of oil equipment manufacturers in the UK, France and Japan, and these are often supported by official and unofficial loans from their countries in their penetration of the world market.

155o (p. 52, #8)

In coal mining, local conditions vary a great deal, and local adaptation of machinery and user-learning are important. The machinery produced in each country is related to the local conditions, and markets for equipment are largely national. However, Japan, whose own coal output is small, has developed a strong mining

TABLE 2

Loans and export credits to developing countries for energy investments

A. 1975-1981

($ million)

	Mining & Processing		Oil and Gas	Electricity	Other	Total
	Coal	Uranium				
I. Multilateral Institutions	376	17	1748	14511	528	17180
World Bank	92	-	1357	8491	451	10391
African Development Bank	-	-	-	234	-	234
Asian Development Bank	51	-	120	1799	-	1950
Inter-American Development Bank	233	-	262	3141	77	3713
European Investment Bank	-	17	9	866	-	892
II. Export Credits	493	45	9687	24548	591	35334
Austria	-	-	28	440	-	518
Belgium	43	41	184	206	-	474
Canada	123	-	473	2995	-	3591
France	10	4	4653	3201	15	7883
Federal Republic of Germany	182	-	113	4415	-	4710
Italy	-	-	53	369	-	422
Japan	24	-	1052	1279	538	2893
Republic of Korea	-	-	-	6	-	6
The Netherlands	-	-	3	601	4	608
Spain	-	-	328	140	-	468
Switzerland	-	-	20	720	-	740
UK	36	-	524	4806	-	5366
USA	75	-	2256	5320	34	7685
Total (AI + AII)	869	62	11435	39059	1119	52514

(continued)

B. 1980-1982

	Energy development	Oil	Gas	Coal	Nuclear	Hydro-electricity Production	Electricity transmission and distribution	Fuelwood and charcoal	Alcohol	Geothermal	Technical cooperation	Biogas	Solar energy	Unspecified	Total
I. MULTILATERAL INSTITUTIONS	**197**	**1494**	**842**	**1135**	**50**	**2639**	**4157**	**122**	**276**	**85**	-	-	-	**771**	**11768**
World Bank	189	1244	324	504	-	1473	1898	-	250	76	-	-	-	506	6464
International Development Asia	8	142	123	525	-	203	752	100	-	-	-	-	-	172	2025
African Development Bank	-	29	-	-	-	23	30	-	-	-	-	-	-	1	114
African Development Fund	-	-	-	31	-	2	29	12	-	-	-	-	-	10	53
Asian Development Bank	-	-	158	-	50	175	580	-	-	-	-	-	-	52	1015
AsDB (Special Fund)	-	5	66	-	-	8	207	10	-	-	-	-	-	29	325
Inter-American Development Bank	-	50	155	75	-	682	498	-	26	9	-	-	-	1	1496
IDB (Special Operations)	-	24	16	-	-	73	163	-	-	-	-	-	-	-	276
II. OPEC	-	**117**	**47**	**23**	-	**401**	**131**	-	-	-	-	-	**5**	**872**	**1596**
OPEC bilateral concess.	-	75	47	1	-	332	83	-	-	-	-	-	-	616	1122
OPEC multi concess.	-	42	-	12	-	56	48	-	-	-	-	-	5	219	382
OPEC multi nonconcess.	-	-	-	10	-	13	-	-	-	-	-	-	-	37	60
III. GOVERNMENTS	**70**	**660**	**449**	**1775**	**61**	**1930**	**1231**	**26**	**11**	**172**	**(807)**	**8**	**2**	**1440**	**8642**
Australia	3	-	-	3	-	3	-	-	-	-	12	-	-	1	22
Austria	-	22	-	-	-	7	-	-	-	-	-	-	-	144	173
Belgium	-	-	-	-	-	-	-	-	-	-	-	-	-	13	13
Canada	6	57	-	-	-	76	106	-	-	-	(30)	2	-	64	341
Denmark	-	7	-	-	-	-	30	-	-	-	2	-	-	1	40
Federal Republic of Germany	-	65	3	170	-	310	234	-	-	-	111	-	-	217	1110
Finland	-	-	-	-	-	2	7	-	-	-	-	-	-	3	12
France[a]	13	63	11	40	35	179	56	3	-	-	(90)	6	1	196	693
Italy	-	-	-	-	-	-	-	-	-	5	(18)	-	-	82	105
Japan[a]	-	203	371	1169	9	884	339	-	11	132	(244)	-	-	387	3749
Netherlands	-	6	5	1	-	6	48	11	-	-	(52)	-	-	19	148

(continued)

	Energy development	Oil	Gas	Coal	Nuclear	Hydro-electricity Production	Electricity transmission and distribution	Fuelwood and charcoal	Alcohol	Geothermal	Technical cooperation	Biogas	Solar energy	Unspecified	Total
New Zealand	4	-	-	-	-	-	-	-	-	4	6	-	-	4	18
Norway	-	3	1	-	-	13	2	-	-	-	(36)	-	-	5	60
Sweden	-	-	2	-	-	61	5	1	-	-	(6)	-	-	25	100
Switzerland	2	-	-	-	-	8	-	-	-	-	1	-	-	1	12
UK[a]	-	165	41	273	-	97	27	5	-	22	(118)	-	-	27	775
USA	42	11	-	5	-	94	77	6	-	-	(75)	-	-	206	516
European Community[b]	-	58	15	114	17	190	300	-	-	9	6	-	1	45	755
IV. EXPORT CREDITS[c]	**-**	**5553**	**1325**	**411**	**2123**	**1686**	**850**	**-**	**42**	**63**	**-**	**-**	**-**	**6384**	**18437**
V. TOTAL (BI - BIV)	**267**	**7824**	**2663**	**3344**	**2234**	**6656**	**6369**	**148**	**329**	**320**	**(807)**	**8**	**7**	**9467**	**40443**

Note: New and renewable sources of energy include, in addition to those separately listed - hydro-power production, fuelwood, alcohol, geothermal - also biogas, solar, wind, ocean, peat, oil shale and tar sands, and draught animal power. However, only very small amounts were reported for the latter categories under the Creditor Reporting System (CRS) on which this table is based. Data on technical co-operation are only partially reported under CRS and have been estimated by OECD (1984), but cannot be allocated to sub-sectors.

[a] Includes also nonconcessional development lending: France $170m; Japan $1514m; the U.K. $150m.

[b] Includes European Investment Bank ($413m).

[c] Includes only officially guaranteed credits with maturity over 5 years.

Sources: Part A: (i) Development Banks' Annual Reports; (ii) World Bank (1983a); (iii) Duersten (1983); (iv) World Bank (1980).
Part B: Compiled from tables 5, 6 and 7 in OECD (1984).

equipment industry based on exports. Japan, the Federal Republic of Germany and the UK are the principal exporters, and exporters in each country are supported by their national governments and banks.

156o (p. 52, #9)

Thus the manufacturers of energy equipment derive their competitive strength from the mastery of technology of one sort or another. They depend to a varying degree on exports, and exports to developing countries generally form a small proportion of their total exports. The markets are often divided up into spheres of influence. Where they are competitive, exporters are helped by official and nonofficial loans from within their countries.

157e (p. 52, #10) CS ZYJ AK

Under these conditions, some of the larger developing countries can build up domestic production of equipment by closing off imports, but given the small domestic markets, their domestic firms remain technologically dependent. Their entry into the international market is constrained both by their technological dependence and by the connexions between equipment makers and their national funding agencies. Equipment makers in these developing countries which have a large domestic output of energy may be able to change this and eventually enter international markets, but to do so they would have to develop their own technological capacity, and their countries would have to give substantial international credits. In view of the scales involved and the important role of governments, cooperation among neighbouring developing countries may be of particular benefit in this area.

158o (p. 53, #11)

International lending for nonconventional energy investments is extremely small, and is confined mainly to charcoal, alcohol and geothermal, all of which are relatively large-scale industries. Much of the funding comes from multilateral institutions.

Research

159m (p. 53, #12) WS

The information on research funding is not nearly as detailed as on investment finance. The only data that give us comparative information of the kind we need relate to a set of projects in the member countries of the Asian Development Bank (Table 3). We have divided the agencies into five types: the international banks, the United Nations family, the submultilateral institutions, the national agencies of the large industrial countries which manufacture electrical plant, and the smaller national agencies which are in the business of funding research per se.

160o (p. 53, #13)

The only area of research that is popular with all agencies is macroeconomic studies. The emphasis on macro studies has a rationale: they are essential for putting micro proposals for investment and research into perspective. It stands to reason that a funding agency would want to get a picture of the macroeconomy and the macroenergetic flows before it decides what to fund at the micro level. But the macro focus also reflects the symbiotic relationship between the funding agencies and the governments. The funding agencies by and large prefer to work closely with the governments and to use the governments' power to get things done. The governments look to international agencies for money, jobs and travel abroad for their personnel. And the research that can be done within governments or state-related institutions naturally relates to policy. Thus the interests of governments and funding agencies coincide in policy-related research.

161m (p. 55, #14)

The United Nations agencies are of two types: specialized agencies and regional commissions. The specialized agencies tend to concentrate on subjects within their own specialization: International Labour Organization on manpower and training, Food and Agriculture Organization on forestry and firewood, and so on. The

TABLE 3

An analysis of externally-financed energy research projects in Asia[a]

Number of projects

					National agencies		
		Banks	UN family	Sub-multilaterals	Large countries[b]	Small countries	Total
I.	**ENERGY**	**23**	**23**	**19**	**11**	**11**	**87**
	A. Data, assessment and planning	14	7	7	3	6	37
	B. Demand and prices	1	1	1	0	0	3
	C. Rural energy	0	1	1	1	1	4
	D. Resources, equipment, technology	1	0	2	3	2	8
	E. Conservation	2	2	3	1	0	8
	F. Manpower and training	5	10	5	2	1	23
	G. Socioeconomic studies	0	2	0	1	1	4
II.	**INDUSTRY**	**0**	**0**	**3**	**1**	**0**	**4**
III.	**TRANSPORT**	**2**	**0**	**7**	**0**	**0**	**9**
IV.	**OIL**	**11**	**2**	**1**	**0**	**0**	**14**
	A. Exploration	4	0	1	0	0	5
	B. Refining	2	0	0	0	0	2
	C. General	5	2	0	0	0	7
V.	**ELECTRICITY**	**37**	**12**	**7**	**38**	**10**	**104**
	A. Generation	4	1	2	1	3	11
	B. Small hydropower	3	1	4	4	1	13
	C. Distribution	4	0	0	1	0	5
	D. Rural electrification	3	2	0	4	1	10
	E. Nuclear power	0	1	0	0	0	1
	F. Other (including training)	23	7	1	28	5	64
VI.	**NATURAL GAS**	**7**	**1**	**0**	**4**	**4**	**16**
VII.	**COAL, LIGNITE, PEAT**	**5**	**3**	**6**	**4**	**6**	**24**
VIII.	**RENEWABLE ENERGY**	**1**	**2**	**4**	**8**	**3**	**18**

(continued)

Table 3 (cont'd)

					Number of projects		
					National agencies		
		Banks	UN family	Sub-multilaterals	Large countries[b]	Small countries	Total
IX.	**BIOMASS ENERGY**	2	3	2	3	1	11
X.	**WOODY FUELS**	4	11	6	5	6	32
	A. Wood	4	11	2	5	6	28
	B. Charcoal	0	0	2	0	0	2
	C. Woodstoves	0	0	2	0	0	2
XI.	**BIOGAS**	0	1	3	0	1	5
XII.	**PRODUCER GAS**	0	0	1	0	1	2
XIII.	**ETHANOL**	0	1	0	2	0	3
XIV.	**VEGETABLE OIL**	0	0	2	0	0	2
XV.	**SOLAR**	1	2	8	2	1	14
	A. P.V.	0	0	3	1	0	4
	B. Other	1	2	5	1	1	10
XVI.	**WIND**	0	0	2	0	6	8
XVII.	**GEOTHERMAL**	3	1	0	3	4	11
XVIII.	**OTEC**	0	0	0	0	1	1
XIX.	**STORAGE**	0	0	1	0	0	1
	TOTAL	96	62	72	81	55	366

[a] Excluding China, Outer Mongolia and North Korea.

[b] Large countries are defined as those with an electrical plant manufacturing base (i.e., USA, Canada, Japan and the UK).

Source: Compiled from Asian Development Bank (1984).

impoverishment of the UN system in the seventies led to considerable competition among agencies for outside funds, which among other things took the form of entering areas that were popular with funding agencies. Energy was one of these areas in the 1970s, and even UN agencies like UNESCO which had only a remote connexion with it exploited what tenuous relationship it could find to organize an energy information system.

162m (p. 56, #15) CS

Insofar as national governments are also organized into specialist ministries like the United Nations, their funding of energy investment and research will also tend to depend on the influence and bargaining power of ministers and ministries. The only difference is that the energy economy will impinge on the government in the form of demands from producing and consuming sectors. The distance between the latter and the United Nations is much greater, and the danger of allocation of funds on the basis of the influence or bargaining power of specialist agencies is correspondingly greater in the UN system.

163o (p. 56, #16)

Leaving the UN agencies aside, the research funding agencies divide themselves into two groups: those belonging to countries which produce power plants, and others. The difference in their research funding patterns is remarkable. A very high proportion of the former's projects is related to areas where they would expect to fund investments. Electricity is by far the most important, but oil, gas and coal also figure. Among the renewables, those in which large-scale technologies have been or can be developed are favoured: for instance, geothermal or alcohol.

164o (p. 56, #17)

The focus of the independent research agencies, on the other hand, is towards resolutely small-scale, stand-alone technologies: biomass, wood, biogas, and solar. They are also technologies that have few established producers in developing countries to feed into. Hence the research is liable to remain unapplied and ineffective.

165m (p. 57, #18)

The question then needs to be asked: why do the independent funding agencies not move into the field of big energy? The answer is twofold. First, in big energy there is an unbroken chain from the equipment manufacturers in industrial countries to the producers in developing countries. Governments of developing countries enter this chain as owners of the firms that buy equipment or as guarantors of their debts, whilst the investment funding agencies enter it as lenders. They fund primarily the research needed to take their funding decisions. Since that research is site-specific it is shown as research in developing countries. But it is project-specific rather than generic, and often it is done by consultants from abroad. Independent research funding agencies have no function in the chain of investments. Second, they are also much smaller than investment funding agencies. The funds of most of them would cover the cost of but few feasibility studies, pre-investment surveys or detailed project reports.

166n CS DF JG DS

In this way, the field of energy research gets divided between the large and the small research funding agencies. Large-scale, site-specific research required for investment projects is funded by large investment funding agencies, whilst small-scale research, generally unrelated to production or commercialization, is funded by small funding agencies. They are not responsible for the lack of connexion between policy, production and use on the one hand and research on the other that is characteristic of developing countries: that disconnection arises from the dominance of multinational corporations in the production of capital-intensive energy equipment, the weakness of domestic firms in developing countries and the passive energy policies of developing-country governments. But international funding agencies also reinforce this disarticulation, and they do little to remedy the weaknesses of research institutions in developing countries.

III. DEMAND ANALYSIS

167m (p. 58, #1)

The growth in the output of goods and services which is an essential part of development will normally require increases in energy consumption to sustain it. In addition, there are a number of structural changes embodied in development that tend to raise the energy intensity of national income.

168m (p. 58, #2)

(i) As people get prosperous, the energy they use for lighting and for appliances increases. Some appliances (e.g., electric fans, radios) begin to be acquired at fairly low income levels, others at higher income levels. Thus even if household energy consumption for cooking does not rise, consumption for other purposes continues to rise with income; and this new demand is mainly for electricity. Electricity is also the major source of motive power in industry. Since about 60-70 per cent of the energy of fuels is wasted in transformation into electricity, the shift in final energy mix towards thermal electricity implies a faster growth in the demand for primary fuels.

169o (p. 58, #3)

(ii) Many developing countries face the need to intensify agriculture in order to produce food for growing populations and to deal with constraints on the availability of arable land. All the major means of agricultural intensification -- water, fertilizers, pesticides, machines -- consume energy.

170o (p. 58, #4)

(iii) A rise in living standards requires a rise in the productivity of workers, and many of the known ways of increasing productivity involve the use of greater energy per worker.

171n HTK

(iv) As developing countries raise their incomes, their demand structures and production patterns shift towards industry, and the growth of industry requires a rise in energy consumption.

172o (p. 59, #5)

(v) A rise in the standards of living entails greater consumption of goods and hence more transport. In addition, urbanization and industrialization place an increasing distance between the producer and the consumer -- and the consumer and his place of work. Thus transport requirements rise more than in proportion to production.

173e (p. 59, #6)

Thus energy is a vital input that can constrain development -- and its constraining effect can be reduced by means of structural changes that reduce the energy intensity of total output, interfuel substitution to replace scarcer by more abundant forms of energy, and energy conservation to increase the overall energy efficiency. Of these, we shall deal with energy conservation in the next chapter; here we deal with the analysis of energy demand, first at the aggregate level and next at the level of user sectors -- agriculture, industry, transport and households.

1. Aggregate Demand

174n MM

In the analysis of energy demand, researchers have to choose between methods with low requirements of data and computation which give quick but limited results, and more powerful methods capable of giving detailed, consistent results which require a heavy investment in data collection and computation. Among the former are studies of the energy-GDP relationship and microeconomic demand studies. Among the latter are macroeconomic models with an input-output base. The choice is not entirely between the quick-and-dirty and the slow-and-clean. Microeconomic studies

can often exploit available data more fully, or use data from special surveys tailored to the problem, whereas large macroeconomic models have often to use data of varying quality and reliability thrown together for the sake of completeness. Microeconomic studies can also accommodate a greater variety of functional forms and therefore allow a closer approximation to underlying relationships, whereas large, multi-equation models have till now been largely confined to linear functional forms and simple relationships. Both types of studies are likely to be affected by the recent increases in the computing power and miniaturization of computers. The effect may be even greater in developing countries in view of the emergence of low-cost microcomputers. Hence both macro and micro demand studies hold a promise of advances in the coming year.

The energy-GDP relationship

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At the most aggregate level, energy consumption may be taken to depend on the gross domestic product, which measures the value of output of goods and services in an economy. A great many studies of the energy-GDP relationship have been carried out, both across countries and over time. The results vary a great deal, and the elasticities in the seventies are generally lower than in previous years (Leach et al. 1985; Siddayao 1986). But they typically show that the income-elasticity of energy consumption is higher for low-income than for high-income countries. This result is the basis of projections which predict a rise in the developing countries' share of global energy consumption (Martin and Pinto 1979). Before this or any other conclusion can be drawn from GDP-elasticities of energy consumption, it is necessary to ask how these elasticities are determined.

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In a process that undergoes no technical change, energy consumption would be proportional to output, and its output-elasticity would be exactly equal to one. Hence if the elasticity is found to differ from unity, it must be due to three possible causes:

(i) Technological improvements may lead to a fall in energy intensity of output; this is the major cause why energy elasticities for industrial countries are found to be below unity.

(ii) Changes in the structure of GDP may lead to a shift towards more or less energy-intensive sectors. For instance, the relatively rapid growth of industry and transport in developing countries is one factor behind their high GDP-elasticities of energy consumption.

(iii) Changes in the composition of energy consumption may change the average efficiency of energy use. In developing countries, commercial energy typically replaces noncommercial energy which is often excluded from statistics; there is thus a purely statistical rise in energy consumption, and in the estimated GDP-elasticity of energy consumption over time. For instance, the inclusion of fuelwood in energy consumption leads to a significant fall in cross-country GDP-elasticities (Strout 1983).

177n

Since the effects of all these three phenomena are mixed up in energy-GDP relationships, it is impossible to say just what the relationships mean (Desai 1978). They can be refined by introducing variables relating to structural change, change in the composition of energy use, population, etc., but disaggregation is a better way of removing the effects of structural change, provided the necessary data are available.

Energy balances

178n

National energy data, if they are disaggregated, can be tabulated in the form of an energy balance. An energy balance disaggregates energy by its components. For each component it equates consumption with the sum of production, international trade and changes in stocks. And it disaggregates consumption by various uses, distinguishing between energy used for transformation and energy put to final use.

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Energy balances have been published for OECD countries by the Organization for Economic Cooperation and Development (OECD) from the fifties onwards. In the seventies the International Energy Agency (IEA), an affiliate of the OECD, stimulated interest in energy balances among developing countries. The energy balances it commissioned were presented and discussed at a workshop in 1978 (International Energy Agency 1979a, 1979b). They have recently been updated to 1982 (International Energy Agency 1984).

180n CS

The Organizacion Latino-Americana de Energia (OLADE), an affiliate of the Economic Commission for Latin America, founded in 1973, has similarly stimulated interest in energy balances for Latin American countries. As a result of its efforts, energy balances have been compiled for all member countries of OLADE, except Barbados, Cuba and Paraguay; for a number of them energy balances are available annually since 1970. The quality of the statistics also has improved over time. The degree of detail available, however, varies from country to country (see e.g., El Salvador 1980, Organizacion Latino-Americana de Energia 1981; Chile 1982, Instituto de Economia Energética 1982, 1983).

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An energy balance is essentially a tabular representation of energy production and consumption statistics. In its preparation, questions regarding detail and consistency have to be answered which provide a useful starting point for national energy studies. An energy balance itself does not contain any information on the determinants of final energy consumption, and is therefore not sufficient for projection, planning or modelling exercises. But a time series of energy balances would give time series of consumption by sectors, which can be used to study the behaviour and the determinants of sectoral consumption. Such sectoral studies can provide submodels which, together, can be used to project or plan national energy production, transformation and consumption (see, e.g., Brazil 1984). The techniques applied to each sector can be adapted to the availabilty of data and the causative mechanisms involved; for instance, it is possible to use very different models for agriculture, industry, transport and households. Thus energy balances, if constructed with a consistent methodology over a number of years, provide a flexible framework for national energy studies. However, if independent sectoral models are developed, the estimates they provide are unlikely to be mutually consistent, and a further mechanism for assuring their mutual consistency would have to be introduced.

Input-output analysis

182n

An input-output table portrays the flows of inputs and outputs across the entire economy, just as an energy balance portrays the flows of energy in the economy. An energy balance may be regarded as consisting of the columns of an input-output table relating to energy sources with three differences: (i) the units used in an energy balance are either physical units or units of energy, whereas an input-output table is in value terms; and (ii) an energy balance gives figures for energy sectors in a more disaggregated form than an input-output table.

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An input-output table, since it shows the sales of one sector or industry to another, is also called the transactions matrix. If the inputs into each industry

are divided by its output, a matrix of input-output coefficients is obtained, which is also called the technology matrix. This technology matrix is a highly versatile tool:

(i) It can be used to calculate both direct and indirect effects of a change in output.

(ii) It shows the link between the outputs of final goods (i.e., goods which are consumed or invested) and intermediate goods (i.e., goods that are used to produce other goods). It can be used to work out the implications for all other industries of a change in the output of a single industry. Thus it can, for instance, be used to calculate the impact of growth or structural change on the demand for energy.

(iii) A change in technology can be represented as a change in input-output coefficients, and its implications for the entire economy can be worked out by modifying the technology matrix. Thus it can be used to estimate the impact of energy-saving technologies or of interfuel substitution on the economy.

(iv) It ensures mutual consistency between the outputs of various industries.

(v) Finally, as a part of linear programming models, a technology matrix can be used for economywide optimization and for analyzing the effects of constraints such as the need to balance trade or to ration limited supplies.

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As a result of these advantages, input-output analysis forms the basis of models used in developed market economies for macroeconomic forecasting. In the form of material balances it also forms the basis of planning in the USSR and other centrally planned economies.

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Its application to energy problems was pioneered by the Energy Research Group at the University of Illinois (Bullard and Herendeen 1975); a small body of specialized work has grown from their methodology (Bullard et al. 1978; Casler and Wilbur 1984). A major application of energy input-output analysis has been in the calculation of the direct and indirect energy intensities, as well as of embodied and disembodied energy intensities of goods (Costanza and Herendeen 1984).

186n

Applications of input-output analysis to developing countries have come mainly from two centres -- MIT Energy Laboratory and Brookhaven National Laboratory. The input-output models developed by Lance Taylor and his associates for development planning (Blitzer et al. 1975; Taylor 1979) have been applied to Mexico (Blitzer and Eckhaus 1983), Jordan (Blitzer 1984) and Egypt (Choucri and Lahiri 1984). In the technology matrices developed by the Brookhaven group, the energy sector is greatly elaborated, energy flows are measured in energy units, and energy consumption is measured in terms of useful energy (i.e., final energy consumed multiplied by the efficiency of utilization). This approach has been applied to Peru, Egypt, the Republic of Korea and Portugal (Mubayi and Meier 1981).

187n MM JG

The large-scale computations required by detailed input-output models have been one reason why even their applications to developing countries have been largely confined to a few research groups in industrial countries which had the facilities and the experience (see, however, Subba Rao et al. 1981; Vanin and Graça 1982; Behrens 1984). But the miniaturization and the fall in the cost of computers have now made these techniques feasible in developing countries as well (cf. Munasinghe et al. 1985). One such experiment for Sri Lanka by a team associated with one of our members is described in Appendix 3. We hope that the easy access to computation technology will lead to greater interest in developing countries in models which take account of interdependence across the economy and ensure consistency between detailed sectoral estimates.

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Substitution among inputs

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Input-output models involve the assumption that inputs are used in fixed proportions to output. This is obviously wrong in the case of various forms of energy that are substitutable amongst themselves. Inter-input substitution can be explicitly taken into account in production functions. There are a number of production functions in use; the one which has been applied most intensively to energy is the translog production function developed by Christensen, Jorgenson and Lau (1973). It has been applied to a number of industrial countries, and has generated a large range of estimates of price elasticities and elasticities of substitution (Hudson and Jorgenson 1974; Berndt and Wood 1975, 1979; Griffin and Gregory 1976; Ozatalay et al. 1979; Pindyck 1979, 1980). The major difference amongst their results is in the fact that some of them conclude that energy and capital (i.e., plant and equipment) are substitutes, whilst others find them to be complements. Thus they make different predictions regarding the effect of a rise in energy prices: the first set predicts greater investment in capital goods, the second less. Recently, Gibbons (1984) has sought an explanation of the difference in results in quality variations among capital goods.

189n
Translog models have found very limited applications in developing countries (cf., however, Uri 1981; Apte 1983). There is no difficulty in applying them at the industry level, where developing countries have relatively abundant data. But in view of the difficulty of interpreting the elasticities of substitution yielded by them, there can be doubts about their operational usefulness.

2. Demand at the Micro Level

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The traditional economic theory of demand is mature and has changed little in recent years (cf. Goldberger 1967). The major determinants of **consumer** demand are known to be income and price, to which may be added special variables relating to each situation: for instance, family size and composition where the demand is personal rather than family-based; or the price and supply of substitutes where they are important. The determinants of **industrial** demand are related to the economic objectives of industry as well as to the specific processes in which inputs are used. They can be studied in the context of a generalized model of industrial production, called the production function (see the previous section), or of industry-specific process models (see section 4 below). Here we shall deal with models of consumer demand.

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Whilst the theory of demand is well-established, the estimation of demand functions presents serious problems of four kinds (Deaton 1978; Deaton and Muellbauer 1980; Wold 1982). First, what is observed in reality is the quantities purchased and sold; from them, it is difficult to disentangle influences that emanate from the buyers and those that come from the suppliers. Second, the regression techniques available for estimation restrict the functional forms that can be assumed between demand and its determinants. If a summary measure of influence, such as elasticity, is required, the functional form is even further restricted. Graphical techniques can be employed to investigate the functional form of relationships, but they are not always effective where a large number of variables is involved. Third, there is the problem of disentangling the relative influence of determinant variables where a number of them are involved; this problem is often difficult and sometimes insoluble. Finally, multivariate relationships require a large body of data and

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relatively computation-intensive regression techniques which, until the advent of the microcomputer, were within reach only of researchers working in the small number of institutions with mainframe computers.

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As a result, a very high proportion of energy demand studies in developing countries uses bivariate methods involving tabulation and two-dimensional graphics (Desai 1985; Howes 1985; Leach 1985). Applied to field surveys, bivariate techniques are highly productive. If a survey generates information on n characteristics, ½n(n-1) bivariate tables can be obtained from it; variation of frequency intervals can expand the range even further. At least a few of them are likely to show some relationship. Thus bivariate techniques are a relatively fail-safe way of getting results. For the same reason they are also not very rigorous. There is always a possibility that bivariate techniques might miss detecting a multivariate relationship or give a misleading impression of it.

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Thus both multivariate and bivariate techniques yield approximations of variable quality. Statisticians and econometricians have put a considerable effort into refinement of estimation techniques in the last 60 years. If it has not led to a high level of reliability, the difficulty lies as much in the complexity and variability of socioeconomic phenomena as in the techniques themselves. However, we would point to two directions of research that hold promise in regard to the analysis of developing-country energy problems.

194n ZYJ

The first is research on the consumer allocation problem. Consumers cannot continue to spend more than their incomes over sustained periods; in this sense there is a budgetary restriction on their total expenditure. Further, different commodities show specific relationships with income. For instance, if a commodity is a necessity, poor consumers spend a higher proportion of their income than rich consumers, and vice versa for luxuries, as was noted by Engel in 1857 (Houthakker 1957). These twin observations have formed the basis of a theory of the consumer's allocation of the budget (Pollack and Wales 1978). In its applications to developing countries, however, it is also necessary to bring in the effects of price changes (Weisskopf 1971; Sener 1977). Income and price effects on commodity groups, including fuel and light, have been estimated for the Republic of Korea, the Philippines, Taiwan (China) and Thailand (Lluch et al. 1977). A study of Indian data also estimated the separate effects of size of family (Ray 1981). This body of literature provides an illustration of the way in which the household consumption of energy can be regarded as the outcome of a budget allocation decision. Further applications to developing countries would call for modifications to the models. In particular, the budget limit in developing countries cannot always be assumed to be a monetary limit, but may be a limit in terms of labour time or farm area, as we shall argue in section 6 below. The character of the limits may vary at different income levels. What should be stressed, however, is the need to place household consumption in the context of the overall consumption decisions of the households.

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The second direction relates to the study of the family as a decision-making unit. It is commonly observed that family farms use more labour per hectare than farms that hire labour (see, e.g., Deolalikar and Vijverberg 1983). Within the family, it is observed that women and children commonly predominate amongst the collectors of fuelwood (Cecelski 1984). It is clear that there are social and economic rules of work allocation and consumption between different members of the family, which are different from the rules which operate within a business firm, for instance. These rules also depend on the income level; work allocation in poor families is very different from work allocation amongst the rich. The knitting together of these frequent but stray observations into theory has attracted researchers in diverse disciplines, including economics (Simon 1957; Pollack and Wachter 1975; Becker 1981; Mack and Leigland 1982), sociology (Demos and Boocock 1978), anthropology (Pryor 1977) and history (Laslett 1972). No unified picture emerges yet from these diverse approaches. But fuelwood collection can be recognized as an aspect of work distribution within family, and its study is likely to be advanced by a synthesis of various theoretical approaches to the family.

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3. Agriculture

196m (p. 60, #1) DF CS

Agriculture may be viewed as an activity that produces useful biomass. The biomass it produces can be put to a very wide variety of uses -- food, fodder, fuel, fertilizer, and industrial raw materials. Its output is so diverse that it can supply most of the needs of rural populations locally. So many agricultural systems in developing countries are self-sufficient to a high degree (though the countries themselves are often not self-sufficient). The trade flows of the systems with other areas are small, and consequently the cost of infrastructure, such as roads and power supply, that is needed to support such flows, is high. Whilst the costs of infrastructure vary and are relatively more manageable for high-income countries and for densely populated areas, they are a major constraint on the rate of rural development. A country that invests in rural infrastructure tends to see low returns in terms of output and trade. One which invests in urban infrastructure may thereby build up industrial output and trade faster, but will face problems of dualism between urban and rural areas and of rural-urban migration.

197m (p. 60, #2) DF

The agricultural systems of developing countries display two common features: a high proportion of population in agriculture, and low value of output per worker, which in turn sets a limit to rural living standards. In those developing countries where the bulk of food intake comes from cereals and roots, a quarter of a ton per adult head per year would provide a quantitatively (though not qualitatively) adequate diet; a tonne per agricultural worker would, very approximately, provide enough for four adults or for a family of husband, wife and three children. In practice, the agricultural population in countries with an output of under a tonne per agricultural worker is largely engaged in subsistence production; all countries which have significant urbanization and industrialization have output per agricultural worker of over a tonne.

198o (p. 190, #7)

In Table 4 we list the countries where food productivity per agricultural worker is less than a tonne/year. The table has its imperfections. To add roots and tubers to grains we have divided root output by three and derived its approximate dry equivalent. We had figures of all agricultural workers, not of workers engaged in food production. To make the two figures comparable we tried to estimate the food that would be produced if all agricultural land were under food crops: we divided food output by the area under food crops and multiplied it by the area under all crops. We could get only area under major crops, so our estimate of the area under all crops and hence of national food productivity is lower than it should be, but the underestimation is not too great. More serious is the assumption that the area under other crops could produce the same yields of food if it was made to produce food crops. Nevertheless, for our gross indicative purposes we believe we have got reasonable figures.

199o (p. 190, #8)

The picture they reveal is not so reasonable, however. Except for one country (Haiti) in Latin America and four (Bhutan, Nepal, Bangladesh and Vietnam) in Asia, all low-productivity countries are in Africa, and they are spread all over the continent. Five other African countries (Chad, Ivory Coast, Malawi, Zaire and Comoros) had productivity between 1 and 1.1 tonne.

200o (p. 191, #9)

It is very likely that Table 4 does not tell the whole story. The productivity figures at the top of the table are so low that families could not be sustained on agricultural food production alone. Clearly, agricultural workers in those countries are likely to be engaged in other activities also; and there must be other sources of food for them -- for instance, animal husbandry.

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Potential productivity per agricultural worker in terms of food, 1983

Country	1 Agricultural workers (1000s)	2 Weighted food output (1000MT)[a]	3 Productivity (2/1)	4 Area under food crops (1000HA)	5 Area under cultivation (1000HA)	6 Potential productivity (3 x 5/4)[b]
Mauritania	436	54.5	0.125	173.0	208.0	0.150
Bhutan	619	186.9	0.302	132.0	136.0[c]	0.311
Mali	3416	975.2	0.285	1789.0	2058.0	0.328
Haiti	1981	694.4	0.351	783.0	897.0	0.402
Burkina Faso	3117	1219.7	0.391	2559.0	2633.0	0.403
Cape Verde	59	9.8	0.166	15.0	40.0	0.443
Lesotho	604	148.8	0.246	154.0	298.0	0.477
Gambia	239	65.8	0.275	87.0	160.0	0.506
Somalia	1563	261.7	0.167	344.0	1116.0	0.543
Rwanda	2394	1139.8	0.476	736.0	1034.0	0.669
Swaziland	190	62.1	0.327	66.0	138.0	0.683
Nepal	6612	4506.0	0.682	2543.0	2605.0[c]	0.698
Kenya	5248	3278.5	0.625	2890.0	3349.0[c]	0.724
Mozambique	2560	983.0	0.384	1535.0	3080.0	0.770
Liberia	532	358.0	0.673	307.0	371.0	0.813
Botswana	315	31.0	0.099	164.0	1360.0	0.819
Guinea	1867	687.2	0.368	637.0	1574.0	0.910
Tanzania	6269	5211.8	0.831	4460.0	5200.0	0.969
Burundi	1746	1104.2	0.632	850.0	1306.0	0.972
Bangladesh	26804	23598.3	0.880	11669.0	12889.0[c]	0.972
Vietnam	17703	16569.0	0.936	7413.0	7737.0[c]	0.977

[a] Output of food crops has been added together in millions of tonnes. Roots and tubers have been reckoned at 0.3 times the tonnage of other food crops, in proportion to their lower calorie content.

[b] Potential Productivity = Productivity x $\frac{\text{Area under cultivation}}{\text{Area under food crops}}$

[c] In most cases the area under cultivation is the area defined by the FAO (FAO 1984, Table 1) as arable land plus land under permanent crops. However, in the cases indicated this area was actually less than that of the area under food crops. In those cases, the area under all crops for which figures were available was added together. The area under fruits and nuts was not available.

Source: Food and Agriculture Organization (1984).

201o (p. 191, #10)

Nevertheless, productivity figures for many African -- and some Asian -- countries look extremely low; at such low productivity levels there cannot be much hope of restructuring their economies. Raising agricultural productivity must come high among the priorities for these countries -- and among research priorities.

202o (p. 191, #11)

However, agriculture should not cease to be a priority area once productivity of 1 tonne/year is attained. A number of densely settled industrializing countries, for instance China, India and Egypt, have productivities between 1 and 2 tonnes. For them too pushing up the productivity level must remain important.

203m (p. 60, #2) DF

The low living standards make the rural population susceptible to urban pulls when the urban demand for labour is growing. Migration to urban areas is not in itself undesirable. It is a major cause of a general rise in productivity and living standards, and has characterized the development of all industrial countries. But where the growth in urban employment is in services rather than in the production of goods, some countries have experienced a fall in agricultural output without a compensating rise in other output and a consequently growing import dependence in food; and urban employment has been shared out among partially-employed rural migrants. Thus a sustained rise in agricultural output per worker makes development more manageable.

204m (p. 61, #3) CS

Any such increase will have implications for the demand for labour: a rise in productivity would reduce labour requirements and would lead to growing unemployment unless total output were to rise. A rise in productivity will normally also raise the real income, increase the total demand for goods and services and raise output and employment. But its positive and negative effects on employment need not cancel out; nor do they always occur in the same place. Hence employment implications of productivity growth would need to be investigated and taken into account in any development programme.

205m (p. 61, #4) CS

Further, growth in output and productivity may have serious implications for income distribution. Agriculture is a land-intensive industry, and except in socialist countries, land is not equally or commonly owned. Where land ownership is unequal and wage employment is common, the benefits of productivity increase would go to landowners unless wages also rise concomitantly and some other form of redistribution (e.g., of land) is applied. Thus agricultural development can lead to a serious worsening of income distribution. Hence the distributive implications of development programmes need always to be studied and taken into account.

206n HTK

In recent times, the growth of agricultural productivity in a number of developing countries has been accompanied bv rapid increases in the consumption of commercial energy, especially oil. This oil dependence has made agricultural systems as vulnerable to external shocks as other parts of the economy, and made agriculture a part of the total policy problem of dealing with such shocks.

Types of energy inputs

207m (p. 62, #9)

In a number of early studies, energy inputs to agriculture were aggregated; in some, the output of agriculture was itself aggregated in energy terms (see, e.g., Makhijani and Poole 1975; Leach 1976; Pimentel 1980). These highly aggregated studies showed that food production systems which achieved high productivity of human labour also showed high inputs of other types of energy to output. More careful

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analysis may lead to more qualified conclusions (cf. Smil et al. 1983). But new conceptual formulations and models would go further to make the analysis of energy use in agriculture fruitful.

208m (p. 62, #10) AR

Perhaps the starting point of such formulation should be the disaggregation of agricultural processes and the involved energy inputs. A methodology that disaggregates the processes and inputs has been developed and applied to rice cultivation by Reddy (1985). Referring to agricultural systems in general, we should first distinguish between direct and indirect energy inputs; the more important among the latter are energy used in irrigation, fertilizers and pesticides. Direct energy inputs can be further divided into mobile and stationary inputs. The type of input determines the possibilities of inter-fuel and inter-input substitution; the totality of processes, together with the substitution possibilities within each, determines the technological options available.

Unmeasured inputs

209m (p. 61, #5) AR

Agriculture depends on crucial inputs of solar energy, carbon dioxide, nitrogen and water from the environment. It would be possible to measure these inputs only in highly controlled, experimental conditions; so most agricultural studies do not measure them, and work in terms of partial models.

210o (p. 61, #6)

The existence of uncontrolled and unmeasured inputs has long been recognized; it was to deal with them that statistical techniques of factor analysis were developed. Simply put, the influence of such factors can be isolated and separately investigated if variations in them are reflected in different samples; then variations among samples can be used to study the effect of uncontrolled factors and variations within samples can show the effect of controlled ones.

211m (p. 62, #7) AR

The general lesson is that it is useful for agricultural studies to encompass a wide range of variations and to stratify their observations in order to bring out the effect of uncontrolled variables such as climate and soils. There is a synergism between macro and micro studies which exclusively micro studies are likely to miss out. This is true of studies of energy use in agriculture: although studies for a single village or a smaller entity may be easier for a researcher or a small team to manage and may get funds more easily, a number of comparable, simultaneous studies in varying circumstances would be more illuminating (cf. Dumont 1957).

212m (p. 62, #8) AK

One axis of variation missed out in agricultural research is the three major food production systems of the world: the seasonal cereal agriculture of the Eurasian land mass, the perennial tuber agriculture of wet Africa, Southeast Asia and the Pacific, and the seasonal coarse grain agriculture of arid Africa. The Eurasian system, developed over millennia, has been adapted to a very wide range of environments, and has also diversified into technologies as a result of its mechanization in the industrial countries. The other two systems, on the other hand, have remained static in technology and productivity, and are declining under competition from the products of the first system. The decline in agricultural production in parts of Africa and the rising food imports into Africa and some Pacific countries are reflections of this technological stagnation. The possibilities of adaptation and improvement of the peripheral agricultural systems are a research area of considerable importance to a number of developing countries.

Mobile inputs

213o (p. 63, #11)
Mobile inputs are inputs required for soil preparation, sowing, weeding, spreading of manures, fertilizers and pesticides, harvesting and transport of output. Human labour is essential to these operations, but its productivity can be increased by animal-powered or mechanical equipment.

214o (p. 64, #12)
When the length of the agricultural season is determined by weather or by the succession of multiple crops, shortening the time spent in soil preparation and in harvesting can raise yields. Hence these operations tend to have the peak energy input requirements, and speeding them up can increase returns.

215o (p. 64, #13)
The use of animals in ploughing speeds up soil preparation, and this is their primary use in most agricultural systems. Although the first harvesters in the USA were drawn by horses, the use of animal-powered devices in harvesting is virtually unknown in developing countries. Animals are used mainly in preharvest operations (and for threshing in some regions), and their use has a sharp seasonal peak.

216o (p. 64, #14)
Human labour inputs have two peaks -- in soil preparation and in harvesting. Hence these were the first operations for which mechanical devices to raise human productivity were developed in industrial, countries in the form of tractors and combine harvesters, respectively. Tractors and, less commonly, harvesters have been introduced in some areas of developing countries, notably in Brazil, Turkey, India and China.

217m (p. 64, #15) CS
The effects of mechanization are different according to where it is introduced in peak operations or below-peak operations. It reduces the man-hour requirements in all operations, but it does not release workers if introduced in below-peak operations. If introduced in peak operations, however, it releases workers for the whole year. In other words, mechanization of below-peak operations creates seasonal unemployment, whilst mechanization of peak operations creates perennial unemployment. Thus tractors and harvesters raise fears of unemployment that do not accompany other forms of mechanization. Mechanization of peak operations can raise productivity per worker in a way that mechanization of other operations cannot, but for that productivity increase to be realized, it is necessary that the workers rendered surplus should be absorbed in employment created by production increases.

218o (p. 65, #16)
As pointed out at the outset, a rise in productivity will raise real income, output and emplovment, and will thus tend to offset the labour displacement effects of mechanization. Hence the direct effects of mechanization, which will always displace labour, may be different from the total effects. It is therefore not surprising that the large volume of research in this area is inconclusive (see, e.g., Hayami and Ruttan 1971; Poleman and Freebairn 1973; International Labour Organization 1974; Binswanger 1978; Berry and Cline 1979). Despite being heavily ploughed, this area of research could benefit from fresh work based on a clearer conceptualization of direct and indirect effects of mechanization.

219n CS AR
The possibilities of agricultural mechanization are constrained by topography, soil characteristics and water supply. For instance, level land with light or easily broken soils is easier to plough mechanically. Differences in these ground factors lead to unevenness in the spread of mechanization. The adaptation of technological systems to the variety of local conditions in developing countries calls for widespread applications of research.

220o (p. 65, #18)
The interrelations between equipment design, tillage conditions and performance have been studied and have led to progressive improvements in the design of tractors, harvesters and implements. With the rise of oil prices, the energy efficiency of equipment was added to the parameters under study (Taylor 1977). Comparable work on draft animals and implements is meagre and little known (cf. Ramaswamy 1979; Ward et al. 1980).

221o (p. 65, #19)
Finally, tillage itself is an input to agriculture that can be optimized. With the rise in oil prices, possibilities of reducing the tillage inputs have attracted considerable attention in the mechanized agricultural systems (cf. Wittmus et al. 1975). Similar possibilities of optimizing tillage undoubtedly exist in the agricultural systems of developing countries, and call for exploration.

Stationary inputs

222o (p. 66, #20)
Agricultural activities after harvesting are stationary, and energy inputs to them may be called stationary inputs. The energy-intensive activities among them are three post-harvest operations, namely drying, threshing and milling.

223o (p. 66, #21)
Of these, threshing and milling are mechanical operations like lift pumping, and can use the same forms of energy. The volume of research on them has been much smaller than on irrigation, but all the technologies and forms of energy for pumping are applicable to them. We shall discuss pumping more fully in the next section. Discussion of solar dryers is to be found in section IX.2 below.

Indirect inputs

224o (p. 66, #22)
Indirect inputs consist of the energy used to produce the goods and services used in agriculture. The principal ones among them are water, fertilizers and pesticides. One way of reducing the indirect energy inputs is to increase the output response to water and other inputs. The difference between the actual responses and responses in controlled experiments is so great that considerable improvements in responses can apparently be achieved by changing the methods and timing of application (see, for instance, Rogers 1983).

225o (p. 67, #23)
Energy use in irrigation has attracted a great deal of research (Meta Systems Inc. 1980; Bhatia 1984a, 1984b). In lift irrigation there are a large number of alternative technologies which can use solid, liquid and gaseous fuels, electricity, solar energy and wind power. Some of these, like solar energy and wind, are dependent on local ambient conditions. Each technology has different scale variations and scale-dependent capital costs. And finally, the depth and volume of water supply vary from place to place; so do prices. In the circumstances, the mapping of appropriate technologies for each combination of conditions is an impossibly complex task. The numerous cost-benefit analyses take different cuts into this complex seam of facts, but do not suffice to order them in a manageable way. It might be better if, instead of trying to define the market segments of each technology in advance, each was allowed to carve out its segment in competition with the others. If they are to do so, market distortions introduced by economically inefficient pricing, such as average cost pricing of electricity, need to be removed. Hence policy-oriented pricing studies are prerequisite to the emergence of better market structures in irrigation.

226o (p. 67, #24)
There is another set of issues which cannot be addressed in the farm-level studies of irrigation, namely that of optimum scale and of spatial distribution of irrigation devices. Generally speaking, gravity irrigation is much less energy-intensive and cheaper than lift irrigation, but only on a much larger scale. It also tends to be inefficient owing to poor matching of water supply and demand. Most lift irrigation devices are subject to economies of scale, some more than

others, but there are limits to the size of all. Finally, the lower the water table the greater the minimum horse power required to lift it. These three factors lead to optimal spatial distributions of devices which are almost never realized in practice, but which could be approximated better by correct pricing practices. Hence water pricing and water allocation rules are of as great a consequence to energy efficency as energy pricing itself. This is a grossly underresearched area.

4. Industry

227n
In respect of the range of energy sources as well as the processes and devices in which they are used, industry is more versatile than other sectors. In transport, the need to make vehicles light, fast and safe has led to the predominance of internal combustion engines, and research too has been concentrated on them. The size of domestic energy-using equipment, on the other hand, is constrained by the size of the household. Energy use in industry is not so constrained bv considerations of size or portability. The range of options available for energy conservation and interfuel substitution is also correspondingly greater in industry.

228n
Producers in industrial countries, especially the larger firms among them, do a great deal of research on their technologies and processes, including energv-related options. Some of the results of this research are proprietary. Others are embodied in the equipment they produce, and information on them is given to potential buyers. Some of the information is published in industrial journals and conference proceedings. Published information is by itself voluminous, especially for energy-intensive industries like steel and cement; and to evaluate it within the time and resources of the Group would have been impossible.

229n
Hence the Group limited itself to reviewing three types of research. First, there is research that presupposes no or little industry-specific knowledge, and which deals with general measures of demand management. Second, there is research on types of energy user and storage equipment, which in our view holds much promise for developing countries. Since the scope of both these types extends beyond industry, they are dealt with in the next chapter. Finally, there is research on energy intensity of industries, which is dealt with next.

Energy-intensive industries

230n
The energy-intensive materials, taking direct as well as indirect energv requirements into account, have been identified on the basis of US input coefficients; the 17 most energy-intensive ones amongst them are listed in Table 5. Energy-intensive materials are defined as relatively homogeneous commodities whose direct and indirect production processes require unusually large amounts of primary energy (Strout 1985). The global energy consumption of these materials is calculated on the assumption that the US energy coefficients applied all over the world; on that assumption their energy consumption amounted to 27 per cent of global commercial energy consumption, and a much higher proportion of world industrial energy consumption. Thus concentrating energy conservation efforts on industries producing energy-intensive materials, or shifting the demand pattern away from these materials, would make a quick and significant contribution to a reduction in overall energy intensity of production.

TABLE 5

World production of principal energy-intensive materials 1969/1971 (3-year means) and 1979-1980 (2-year means)

Commodity Group	Energy coefficient MTCE/MT (1)	Av. annual production ('000 metric tons) 1969-1971 (2)	Av. annual production ('000 metric tons) 1979-1980 (3)	Energy use at 1967 USA technology, etc., ('000 MTCoal equiv/yr) 1969-1971 (4)	Energy use at 1967 USA technology, etc., ('000 MTCoal equiv/yr) 1979-1980 (5)	Ratio, 1979-1980 to 1969-1971 (6)
Petroleum refinery products	0.21	2186004	2982677	459061	626362	1.364
Wood pulp	0.99	101216	124922	100204	123673	1.234
Paper and paperboard	0.4	127291	174250	50916	69700	1.369
Chemical fertilizers (NPK)	0.77	71484	121796	55043	93783	1.704
Insecticides, fungacides, etc.	3.63	1620	2760	5881	10019	1.704
Plastics and resins[a]	5.38	29294	58599	157602	315263	2.000
Synthetic rubber	5.46	5015	9022	27382	49260	1.799
Cellulosic man-made fibers	8.10	3510	3279	28431	26560	0.934
Non-cellulosic fibers	9.45	5097	10413	48167	98403	2.043
Cement, hydraulic	0.32	570333	861902	182507	275809	1.511
Building bricks[ab]	0.26	473766	442133	123179	114955	0.933
Steel products[c]	1.87	582033	723649	1088402	1353224	1.243
Primary copper	4.47	7394	9394	33051	41991	1.270
Primary lead[d]	1.10	3923	5580	4315	6138	1.422
Primary zinc	3.04	5208	6296	15832	19140	1.209
Primary aluminum	8.97	10217	15613	91646	140049	1.528
Primary magnesium	13.55	220	371	2981	5027	1.686
Primary tin	1.42	220	234	312	332	1.064
Total energy use in 17 nonfuel commodity groups at 1967 USA technology, industrial structure, etc.				2015851	2743326	1.361
Percent of world total primary energy production				26.9	26.8	0.996
Memo: World total primary energy production[f]				7504410	10254408	1.366

[a] Coverage probably less complete than for other commodities.
[b] Bricks converted to metric tons at factors of 2038 MT/million standard bricks or 2.0 MT/cubic meter.
[c] Crude steel equivalent.
[d] Includes secondary antimonial lead in 1979-1980.
[e] Wood pulp, paper and paperboard, fertilizers, cement, steel and nonferrous metals except magnesium.
[f] Hydro, geothermal and nuclear electricity included at thermal generating station equivalent, assuming 25 percent generating efficiency in both years.

Source: Strout 1984.

231n
Such steps would, indeed, be incumbent on a number of developing countries, for in industrial countries the per capita consumption of the ten most energy-intensive materials in 1979-80 was in the range of 1-2 tonnes/year; in developing countries with incomes under $1000 per head, it was typically 100 kg or less. Thus production of energy-intensive materials on a large enough scale to raise their per capita consumption to the levels current in industrial countries would entail such a large increase in global energy consumption that the saving of both energy-intensive materials and energy is likely to be a necessary part of the growth strategy of developing countries.

232n
Whilst it may be assumed that those industrial goods that are energy-intensive in industrial countries will also be energy intensive in developing countries, their relative weightage will vary from one developing country to another. Thus the list of industries on which conservation and substitution measures must be concentrated has to be worked out individually for each developing country. Apart from energy-intensive materials, such a list may well include industries which, though not energy-intensive, consume a large proportion of the energy used in a country because of their large size: for instance, food and drink, or textiles in many developing countries.

233n
It also cannot be assumed that the energy intensity of an industry will be the same in industrial and in developing countries. Technology varies from country to country and from plant to plant, and it is necessary to work out conservation and substitution strategies in the context of the local industry.

5. Transport

234m (p. 75, #1, p. 196, #7)
The dominance of oil-fired internal combustion engines has made transport the crux of the strategic problem of oil dependence of developing countries. The countries where development began in the nineteenth century built up railway networks, but many countries of Latin America and Asia whose development gathered pace in the petroleum age depend exclusively on road transport and on oil. So we have tried, in Table 6, to identify the developing countries with a high transport intensity. The results surprised us in a number of ways. For one thing, we had expected that product prices would adjust themselves to transport costs and that transport intensity would not vary much; in fact, the variation is enormous. For another, there is no obvious explanation of the variation. It may well be that it is due to differences in relative prices; figures given by Moavenzadeh and Geltner (1984), insofar as they are comparable, show smaller differences. But other explanations offered, such as the size of the country or the proportion of subsistence production, do not hold. The variation is intriguing, and forms a starting point for an enquiry into its causes and into policy options.

235m (p. 75, #1, #2)
For developing countries, transport forms the link between energy policy, trade policy and environment policy. It thus provides a base for integrated policy formulation. Current research, however, provides a poor basis for such policy formulation. The volume of research is comparatively small, and much of it relates to modes of transport and transport technologies rather than to the uses of transport. The poverty of research is rooted in the poverty of data: even for industrial countries the degree of disaggregation in the data is not great.

236o (p. 75, #3)
Research on transport may be divided into research on transport planning and and on transport management. The management of existing transport systems is made difficult by three facts:

(i) Transport routes are natural monopolies. As long as a road is underutilized, it is wasteful to build an alternative one. By the time it is fully utilized, there

TABLE 6

Transport-intensity of GDP, 1981

Country	1 Energy consumption in transport (thousand toe)	2 GDP ($ million)	3 Transport intensity of GDP (1/2) (toe/$m)
Costa Rica	467	2630	177.6
Tunisia	1247	7100	175.6
Argentina[a]	10541	64450	163.6
Ecuador	2186	13430	162.8
Kenya	1021	6960	146.7
Sri Lanka	597	4120	144.9
Trinidad and Tobago	1001	6970	143.6
Venezuela	9228	67800	136.1
Panama[b]	473	3490	135.5
India[a]	19730	150760	130.9
Colombia	4255	32970	129.1
Egypt[a]	3375	26400	127.8
Jamaica	372	2960	125.7
Pakistan	3017	25160	119.9
Zambia	398	3430	116.0
Burma	669	5770	115.9
Thailand	4250	36810	115.5
Mexico	25260	238960	105.7
Brazil[a]	25318	248470	101.9
Zaire	540	5380	100.4
Morocco	1406	14780	95.1
Peru	2154	23260	92.6
Zimbabwe	537	6010	89.4
Indonesia	7251	84960	85.0
Bolivia	661	7900	83.7
Republic of Korea	5495	65750	83.6
Chile	2523	32860	76.8
Uruguay	669	9790	68.3
Ivory Coast	581	8670	67.0
Algeria	2611	41830	62.4
Philippines	2321	38900	59.7
Guatemala	459	8660	53.0
Saudi Arabia[a]	7602	153590	49.5
Libya	1269	27400	46.3
Nigeria	2985	70800	42.2
Malaysia	1041	24770	42.0
Bangladesh	431	11910	36.2

[a] 1982 figures
[b] 1980 figures

Sources: For column 1: International Energy Agency (1984)
For column 2: World Bank (1982b; 1983b; 1984)

will be so much settlement around it that it is impossibly costly to widen it or to build a parallel road, and more attractive to ration road capacity.

(ii) Transport requirements are a function of settlement and activity location patterns. Both road capacity and location patterns are difficult to change, and if they are mismatched, it is difficult to do anything about it.

(iii) There is considerable investment in transport user equipment; if traffic densities demand a change in modes of transport, new user equipment may call for much scrapping of old equipment and for new investment.

237o (p. 76, #7)

For these reasons it is advantageous to invest in research in transport planning, so that problems of transport management can be avoided or postponed (Thomson 1983).

238o (p. 76, #8)

Transport planning encompasses the planning of national location patterns and regional specialization, town planning and design, and modal choice between and within towns (Meier 1974). All three have energy implications.

239o (p. 76, #9)

The point of planning national location patterns as well as town planning is to minimize transport flows and hence energy inputs. The volume of transport between nodes will determine the appropriate modes. The investment requirements for railways (including the track and the rolling stock) are much higher than for road transport, but the track capacity is much higher. Hence railways will be economically justified beyond a certain traffic density. Unlike in road transport, there is considerable choice in traction technologies and fuels in railways. One way of saving oil is electric rail traction. In a given situation the possibilities of substitution between roads and electric rail traction will be limited by traffic volumes. But in the long run, location planning can concentrate traffic flows between fewer nodes and make them large enough to justify electric railways (Inter-American Development Bank 1982; Alston 1984; Moavenzadeh and Geltner 1984).

240o (p. 76, #10)

Bottlenecks in inter-urban transport are few, and where they arise, they usually admit of only limited choices. Bottlenecks in intra-urban traffic are, however, much more common. Road capacity is a function of road width and the average speed of traffic. People in developing countries walk more and use personal transport less. There is also more transport of goods and people by means of human and animal traction. All these means of transport are slow and use up much road capacity; at the same time, replacing them by mechanized transport is costly and may have serious effects on employment (Thomas 1981). Various low-cost forms of mechanized transport are used in developing countries which also reduce road capacity in a number of ways: by slow speeds, dangerous driving, more frequent breakdowns, etc. (Ocampo 1982). The result is that many cities in developing countries have experienced a slowing down of traffic, reduction of road capacity and clogging up of roads, whilst some others have experienced the squeezing out of slower traffic to the detriment of low-income populations.

241o (p. 77, #11)

These problems are peculiar to developing countries and arise from their economic and transport characteristics; they need to be tackled at the stage of planning. The rise of the use of the personal car led to considerable research on urban design in industrial countries (e.g., Buchanan et al. 1980); it was reflected in the new towns, and has made them much easier to live in than the older metropolises. At the same time the metropolises that did not foresee or could not solve the emerging problems (e.g., the movement of the better-off to suburbs, the depopulation and impoverishment of city centres and the rise of the automobile traffic) have experienced shocking social and environmental deterioration. The urban problems of developing countries are different, but lead to equally drastic consequences if not tackled in time.

242o (p. 77, #12)

At the stage of planning, it is necessary to work out the implications of the peculiar traffic characteristics of developing countries. For instance, if walking

is a common mode of transport, it is necessary to provide more space for walkers; failure to do so results in the spillover of pedestrians onto roadways. It is also worth keeping workplaces within walking distance from workers' residences. Thus, whilst the techniques of town planning in developing countries will be similar to those for industrial countries, the data that go into the plans will be very different, and so also the plans.

243m (p. 78, #13) JG

However, all problems cannot be resolved through planning. In existing cities where location patterns and traffic flows are given, the traffic must be managed within the available road capacity. Here there are two basic solutions. First, various techniques of traffic separation, and road access restriction are used to ration road capacity (Organization for Economic Cooperation and Development 1973). But less coercive ways of traffic management are also available. Governments have at least three bases of taxation available in relation to transport, namely fuels, vehicles and roads; of these, road taxation and the financing of highways through tolls are little exploited (Yucel 1974). In any case it is worthwhile to look at the pricing and taxation of all the three -- fuels, vehicles and roads -- together, and to relate them to the needs of traffic management.

244n JG

Second, it is possible to increase available traffic capacity by means of intermodal substitution; suburban (overground and underground) railways and rapid-transit highways are the major modes used. Such modes, when introduced into existing cities, are extremely costly, because systems designed for speed and effective traffic separation have high capital costs, because land in cities is expensive and because the systems have to be constructed with minimum disruption to existing patterns of life and work. Their high investment costs lead to considerable research in their economics and design.

245n JG

Because of their high cost, however, investment in them can seldom be justified on purely financial grounds, and they generally require sustained subsidies. The subsidies can be justified on distributional grounds where the population that lives on the periphery of the cities and consequently uses the new route for long-distance commuting is poor. But essentially, the subsidy to rapid transit is not a subsidy to the poor, but a subsidy to long-distance suburban transport. The supply of such transport facilities also tends to create its own demand by encouraging the settlement of population in the peripheral locations they serve: they shape the vast conurbations as much as they serve them. If the national or regional planning of location patterns, advocated earlier, leads to the saving of costly investment in rapid-transit systems for overgrown cities, its value would be greatly enhanced.

6. Households

246m (p. 43, #1)

In industrial societies a consumer is practically always a buyer. He has a money income which he spends on consumer goods. Very many consumers in developing countries do not fall into this stereotype: some consume goods they produce themselves, others collect them from common lands. There is no common system of analysis applicable to all of them, and it is necessary to distinguish between them in energy research among others. It is equally necessary to integrate the analysis of all three to get an idea of total domestic demand.

Collector-consumers

247m (p. 43, #2) AK AR

Fuel in various forms is collected by a large number of consumers in developing countries. It is not the only thing that they collect; they also collect

water, and often food. Wherever such naturally available products are collected, it is possible that consumption will outrun the naturally available supply, or the carrying capacity (Sahlins 1972; Odum and Odum 1976; Harris 1977). Even before the carrying capacity is reached, the average distance between the consumer's residential base and his sources of supply will increase and so will the time he spends in collection. More often it is the woman in the household whose time is taken by firewood collection and other survival activities (Tinker 1984). Many figures have been collected and micro-level evidence amassed on the average collection times of firewood. From these collection times it is concluded that the collector-consumers would be better off if they became producer-consumers and started their own woodlots. The analysis looks sound and leads to a persuasive policy recommendation, which, however, has proved very difficult to implement.

248m (p. 43, #3)

To our mind, this field of research illustrates the dangers of excessively micro research: the system boundaries have been too narrowly defined. For it has also been found in a number of studies that a major part of the demand for firewood comes from cities. If this is so, the responsibility for the depletion of the tree stock lies, not with the collector-consumer, but with the collector-seller: the system to investigate is not the village but the urban-rural complex. Townspeople almost invariably use other fuels as well, so the boundaries should be drawn, not around fuelwood, but around all competing fuels. It has also been found in places that the bulk of demand is not for firewood but for timber for housing and construction. So again the system boundaries must be extended to include construction materials. Finally, the relative scarcity of firewood varies from place to place and has led to different degrees and patterns of energy transition. Hence it is necessary for research to encompass regional variations. If extended in these ways, the scope and the scale of research projects would be greater, but the lessons to be learnt would be richer and the number of policy alternatives that emerge would be greater: for instance, alternatives in terms of fuels, construction materials, and the technologies for producing both. The cost and the coordination requirements would also be greater, but one of our arguments throughout this report is that organization should be adapted to the needs of research, and not the other way round.

249m (p. 44, #4)

If such broadbased research led to the conclusion that a collector-consumer population was straining the carrying capacity of the land and the pressure could not be relieved by manipulating a third factor like construction materials, either the population would have to come down or it would have to change its technologies and grow wood or cook with greater fuel efficiency. But it is unlikely that a consideration of all alternatives in all the related fields will lead to these as the only or the best alternatives.

Producer-consumers

250o (p. 45, #5)

Producer-consumers are also called subsistence producers. Like collector-consumers they do not buy or sell; insofar as they do not, the possibilities of influencing their behaviour are limited. To neither is it possible to apply demand analysis of the type used in developing countries for buyer-consumers. More appropriate theoretical formulations are not available, so a great deal of data gets collected and described without accumulation of knowledge (see, however, Bliss and Stern 1978; Sen 1981).

251o (p. 45, #6)

Attempts to formulate policies affecting producer-consumers (and collector-consumers), e.g., promotion of agroforestry or biogas, have also been slow to yield results. This too is, in our view, due to inadequate theoretical understanding of the behaviour of these consumers -- of their objectives in life and work and of their allocation of resources.

252m (p. 45, #7) AK

The central one among their resources is labour. Unfortunately, economists, anthropologists and physiologists have followed very different concepts of labour or work, and none of them has proved especially fruitful (see Section X.2 below). Meanwhile a great deal of empirical research has been done without commensurate advance in understanding. Theoretical innovations will have to emerge in this area before empirical research can be sensibly interpreted.

Buyer-consumers

253m (p. 45, #8) CS JG

This is the type of consumer that is familiar in developed economies, and the consumer for whom the standard demand analysis (referred to in section 2 above) has been devised. This type of analysis is equally applicable to buyer-consumers in developing economies, although the ground conditions and the implicit relationships are often very different. It can be particularly useful for analyzing the effect of changes in prices, taxes or subsidies on consumers at different income levels and thereby on overall income distribution.

254m (p. 46, #8)

However, if consumers are partly collectors, partly producers and partly buyers as often happens in the case of rurally consumed fuels, the case is much more complex; theoretical formulations for such mixed situations still need to be developed.

Cooking

255m (p. 79, #2) CS

This is the area of domestic consumption that has attracted the greatest volume of research. The result is a welter of figures which support few significant conclusions. Most of the studies simply measure the total consumption of cooking fuels, and therefore miss out two aspects which may well be of considerable importance. First, cooking always involves food and drink; there must be a relationship between the quantity of food cooked and the fuel used. If, as food surveys show, food consumption can vary between the poor and the rich by a factor of 1.5 to 3 in developing countries, it may have a considerable effect on fuel consumption. Yet the differences in fuel consumption are not observed to be so pronounced (Leach 1985); so there are likely variations in energy efficiency. Second, there is limited but strong evidence that larger households use less fuel per capita (Bialy 1979; Natarajan 1985: 85). Cooking is a chemical process, and it stands to reason that cooking in larger quantities should be more fuel-efficient. It is also possible that there is less wastage and there are therefore economies of scale in food consumption also in larger households.

256o (p. 80, #3)

It would be fair to say that energy research has stopped at the doorstep and failed to penetrate the house; the result is that the proximate determinants of fuel consumption remain uninvestigated, and research is confined to external variables like income and price. Superficial research can lead only to superficial conclusions. The situation is similar to that in respect of research on food consumption, which also has failed to cross the doorstep, and has generated voluminous figures without leading to further understanding.

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Lighting

257e (p. 80, #4) CS JG
Lighting is an item of consumption with high-income elasticity of demand at low-income levels. The poorest households and those without access to kerosene and electricity do without lighting. Among those with access, quality of lighting varies with income. There are many types of kerosene lamps with varying oil consumption per hour and intensity of light. The types of electric lights are fewer, but the intensity and quality of electric lighting do vary with income. A variety of types of electric lighting is available whose energy efficiency varies by a factor of 3 to 4; energy-efficient lights are not used more widely because their initial costs are higher. Insofar as they are, there is scope for tax-subsidy mechanisms to increase energy efficiency in lighting; they need to be designed through country-specific or site-specific research. But apart from costs, the adoption of energy-efficient lights is also influenced by perceived differences in quality. Research can bring a better balance between the range of available devices and user preferences.

Appliances

258o (p. 81, #5)
Electricity is essential to most of the commonly used domestic appliances. Where electricity is available, a large range of appliances is available with considerable variation in capital and in running costs.

259m (p. 81, #6)
Depending on their initial costs, different appliances will have different market penetration curves related to income levels. The purchases of the cheaper ones like irons, heaters, radios and fans will begin at fairly low income levels, whilst the most expensive ones like air conditioners will be bought at much higher income levels (Brooks 1984). The demand for consumer durables has to be analyzed in terms of stock adjustment models; simple price-income models are not appropriate for them. The demand for energy to run appliances is a derived demand depending on their energy input per hour, their intensity of utilization and their numbers in stock, and its analysis requires correspondingly complex models and field surveys to provide data for them.

260o (p. 81, #7)
Power demand for air conditioners is already a significant part of total demand in some African cities, and causes serious peaking problems. The demand emanating from cooling devices -- fans, coolers, air conditioners and refrigerators -- may be important in other tropical developing countries; certainly daily peaks in summer pose problems in many of them. The solutions may be looked for in a number of directions -- climatic adjustments to houses, time-of-use pricing of electricity, and improvements in the energy efficiency of appliances for instance. This entire area has attracted little research.

Rural households

261o (p. 82, #8)
The only part of rural energy demand that has attracted much research is the demand for cooking and heating fuels (Howes 1985). Demand is a behavioural variable, and a theory of human behaviour must underlie its analysis. The received demand theory, framed in terms of a consumer whose entire income is monetary, is inappropriate for rural households in developing countries.

262o (p. 82, #9)
Part of their income is in the form of collected goods, of which fuels can form an important part. Since collected goods are free (though not necessarily abundant), resource costs do not enter the households' calculations. On the other

hand, labour costs do. The perceived labour costs are related to the quantity collected and the distance carried in a nonproportional way: the onerousness of quantities as well as distances is insensitive up to a point and highly sensitive beyond a certain point. It is not possible to value the labour involved in collection at the going wage since the alternative of wage labour is not always open. The unequal employment opportunities for men and women will also affect the alternatives open to them, and are clearly related to the relatively greater role of women in collection. Where it is, or where money incomes in rural areas have risen as in Egypt or the Republic of Korea, the rural population readily ceases to collect fuel. Thus it is necessary to explore the relationship between collected fuel (and other collected goods) and their labour costs.

263o (p. 82, #10)

Labour costs have been estimated in terms of labour time, but for the earlier stated reason the perceived labour costs may not be proportional to the labour time. "High" estimates of labour time spent in fuel collection have been at least partly responsible for the research effort that has gone into fuelwood forestry and improved woodstoves. The value that a population places on these innovations will, however, depend on the perceived labour costs, and not the labour time. The object of saving labour time would appeal only to a population that is short of it; for one that has ample labour time or only low value uses for it, the question to ask is: what are the most valuable uses of labour time that can be found for it?

264o (p. 83, #11)

However, in view of the research on fuelwood forestry and woodstoves, one may ask a different question, namely where can a use be found for this research? The answer would be, where these activities are commercialized: namely, where selling firewood is an established rural activity, and where woodstoves are used to cook food for sale. Once they are proven in commercial uses, they are likely to diffuse more easily.

265o (p. 83, #12)

Apart from collected fuels, rural households also burn fuel grown or produced on the farm in the form of crop residues and animal residues. There are very occasional references in the literature to cultivated fuel crops (e.g., Pathak et al. 1980); but mostly it is the residues of crops grown for other purposes that are burnt. The residues of a food crop should normally give enough energy to cook the edible part at a fairly low level of efficiency of 10-20 per cent (Desai 1985). But it is common for farming households to buy or collect woody fuels for their better quality.

266o (p. 83, #13)

In the case of farming households too the behavioural models underlying studies of fuel consumption are inexplicit. Farmers vary in their degree of commercialization. The uncommercialized or subsistence farmers use agriculture to convert their labour into goods and services, just like collectors of fuel, and the model applicable to both would be one of allocation of labour flows. Commercialized farmers, on the other hand, run business enterprises, and may fit theories of the firm or the farm. Most developing country farmers fall in between, and pose unsolved conceptual problems.

267o (p. 83, #14)

Both collectors and producers obtain combustible biomass from vegetation, and their practices have been the subject of academic concern. This concern, which we shall discuss in Chapter XI below, is based on naïve models. It is not necessarily misplaced, but the conditions of environmental deterioration need to be defined more closely and their connexion with fuel demand more directly observed. Thus studies of fuel consumption should be integrated with those of the environment.

268o (p. 84, #15)

Further, if biomass-burning practices lead to environmental deterioration, they will be reflected in greater inputs of labour time into fuel collection in the case of collectors and declining yields in the case of producers. The research studies must be designed to take in these effects: that is, they must either extend over long enough periods or encompass spatial variations to simulate the transitions.

269o (p. 84, #16)

Thus the models that researchers bring to the study of rural fuel consumption from the mother disciplines of economics, anthropology and agricultural science need to be integrated and tested if more meaningful theories are to emerge.

Urban households

270m (p. 84, #17) CS

The energy consumption of urban households is easier to analyze in a number of ways. First, urban households purchase energy. They are too concentrated spatially to be able to obtain cooking fuel from a local biomass base, and must buy it from outside. Second, they are significant consumers of energy for lighting and appliances. In both ways they are more akin to those in industrial countries; insofar as they are, models developed in those countries to analyze domestic energy demand can be applied to them with less danger of misapplication.

271m (p. 84, #18) AR

The urban concentration of fuel demand requires the transportation of large quantities from outside. This means oil and coal in countries that produce them or can import them, but in many countries which are too poor, remote or short of foreign exchange, it means firewood and charcoal. The consumption of both leads to expanding circles of treeless zones around the cities. Whereas wood is replaced by agricultural and animal residues in rural areas which run out of it, the low energy density and consequently high transport costs of these substitutes make them noncompetitive with wood in towns even at high firewood prices. Where they are competitive, the low cost of woodstoves compared to stoves using gas or kerosene may still lead poor consumers to use wood (cf. Alam et al. 1985).

272m (p. 85, #19) AK CS JG

The rising firewood prices have led to firewood plantations in some regions, (e.g., casuarina plantations in South India). But there are cities especially in arid parts of Africa, where commercial tree farming has made little progress despite high firewood costs. The reasons are very unclear; but two factors are indicative. First, arid Africa is also the region with high imports of food or food shortages or both. In theory, a commercial farmer who is supplying a city would grow food, fuel or any other crop that would pay most. The reason why this choice on the farm does not raise urban fuel supplies may be that the cities have outgrown their agricultural supply base. As we showed earlier in section 3 of this chapter, arid and sub-equatorial Africa has the lowest levels of agricultural productivity per worker in the world; its agriculture is thus capable of supporting the least number of people off the farm. Its capacity to do so was further reduced by the shift to commercial crops in the fifties and sixties when the demand for them in industrial countries was strong. The cities grew up around export industries; the exports paid for imported food among other things. As the slowdown of growth in industrial countries slackened the demand for exports, reduction of export dependence and creation of a domestic market as well as resource base became necessary before growth could be resumed. Thus the crisis is a general economic one, and not simply a fuel crisis. Second, arid tropics are an area where trees grow with difficulty; their natural vegetation is annual grasses and shrubs. Once the inherited stocks of trees are destroyed, their replacement is difficult and costly. Some of the countries of West Asia and North Africa also share this problem but are lucky to have oil, which has become their primary domestic fuel.

273o (p. 85, #20)

Thus in respect of urban as of rural households, a narrow formulation in terms of fuel consumption can lead to wrong conclusions, and it would be useful to place fuel use in a broader economic and resource context.

IV. ENERGY DEMAND MANAGEMENT AND CONSERVATION

274n MM JG

Insofar as the growth in output is constrained by the supply of energy resources, indigenous as well as imported, it is in the interest of a country to look for ways to economize energy and to minimize its constraining effect. The set of policies designed to serve this objective is called energy demand management. For developing countries whose growth has been crippled by the cost of energy, a drastic reduction in the energy intensity of output increases is a necessary concomitant of further development. But they are not the only ones to whom energy demand management is of interest: it can improve the economic prospects of all developing countries.

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Energy demand management may be looked upon as the application of energy demand analysis to policy problems; it can thus be carried out at the same levels of aggregation as demand analysis. Thus we may distinguish between energy demand management at four levels:

(i) Structural management: policies aimed at influencing the structure of economic growth.

(ii) Sectoral management: policies for energy user sectors.

(iii) Resource-level management: policies to influence the demand for individual sources of energy.

(iv) User-device management: policies designed to influence the efficiency and fuel choice of energy-using equipment.

1. Structural Policies

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As explained in section III.1, the direct and indirect energy requirements of various components of final demand can be estimated by the use of input-output matrices. The total (direct and indirect) energy requirements can be very different from direct energy intensities; input-output analysis can be helpful in avoiding the biases inherent in the observation of direct energy requirements.

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The relationship between energy use and final demand can in principle be used to reduce the energy intensity of gross national expenditure by shifting expenditure from more to less energy-intensive components of final demand. This can be done in three ways:

(i) by influencing the components of final demand themselves; e.g., by means of taxes and subsidies on final goods;

(ii) by influencing the determinants of final demand; e.g., incomes, through income-related taxes and subsidies; or

(iii) by influencing the regional distribution of final demand and thereby reducing transport inputs; e.g., by means of location control.

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The last alternative has been discussed in section III.5 above; however, tax-subsidy measures call for more detailed discussion here.

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Taxes, subsidies and allocation

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For simplicity we may confine this discussion to taxes since subsidies can be regarded as negative taxes.

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Under certain reasonable assumptions about consumer preferences it can be shown that a proportional tax on their incomes would leave consumers better off than taxes on the commodities they purchase, if the revenue from both were the same. This well known proposition of the theory of public finance, together with the fact that an income-related tax can be made progressive, argues for a preference for direct over indirect taxes (Newbery and Stern 1985).

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However, in practice, all countries rely a great deal on commodity taxes, developing countries probably more so than industrialized market economies. This preference is based on administrative convenience. Administratively, the fewer the taxpayers the easier to collect a tax; producers, processors or traders on whom commodity taxes are levied are fewer and offer a more compact target than the general mass of population. The tax base for direct taxes can be contracted by introducing a high threshold for tax exemption, but if a large proportion of the population is tax-exempt, problems of identifying newly eligible taxpayers, as well as preventing tax evasion by unidentified taxpayers, become serious. Further, income is a much more imprecise tax base than the volume of goods produced or traded.

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More principled reasons can also be given for a commodity-based approach. For instance, it can be argued that whilst poverty leads to undesirable deprivation, deprivation of some goods, such as food, clothing and shelter, is more serious than deprivation in general: this is the basis of the basic needs approach. Conversely, it can be argued that the deprivation of some goods, such as alcoholic beverages, is not so serious for anyone, and that a reduction in the consumption of luxuries is not serious for the rich. This argument can form the basis of taxes on luxuries and subsidies on necessities. However, such commodity-specific taxes and subsidies cannot be confined to a specific income class; they affect all purchasers, whether they are rich or poor.

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A subsidy on basic necessities has the further shortcoming that it takes no account of the fact that as a person or a household consumes more of it, additional quantities of it become less essential. Ideally, a subsidy on a basic necessity should be specific to the poor consumer, and should apply only to a certain minimum purchase. A better approximation to such a subsidy is obtained by rationing, which assures a fixed minimum quantity to all at a subsidized price. The restriction that it imposes on consumer choice can be removed by making rationing quotas saleable, and thereby allowing those poor who do not need the ration to convert it into freely disposable income. However, though it is simpler to administer than a subsidy based on personal income, it requires an administrative machinery that can reach down to each household. Further, rationing of subsidized goods brings into being a dual market, and the administration has to be strong enough to prevent the leakage of subsidized supplies into the unsubsidized market. Thus the efficient administration of subsidies calls for a level of integrity and sophistication in the government as well as economic integration within the country that are not within reach of all developing countries. The objectives of justice and fiscal efficiency have to be pursued within the administrative capacity of a country, and the optimum solution worked out for each. Thus whilst the use of the fiscal machinery for the reduction of energy intensity must be considered for all developing countries, the possibilities of such use are country-specific and must be researched at that level.

2. Sectoral Policies

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Many sector-level policy initiatives are implicit in our discussion of user sectors in Chapter III. Here we shall highlight some major policy alternatives at the sectoral level.

Agriculture

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In section III.3 we gave a classification of energy inputs to agriculture and discussed them separately. For policy purposes it is necessary to combine them into technological alternatives and to make or induce choices amongst them at the aggregate level (for a description and application of the methodology for doing so, see Reddy 1985). Such choices often relate to energy sources; for instance, a decision to mechanize involves the substitution of mechanical for human or animal power. Whilst it essentially involves interfuel substitution at the farm level, it requires policy formulation when it has macroeconomic implications for total employment, balance of payments and energy resource use.

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Policies can also be devised to increase the efficiency of energy use in agriculture. Three areas appear most promising in ths regard.

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(i) An increase in land yields raises the productivity of all energy inputs that are related to the area cultivated: inputs to ploughing, application of fertilizers and pesticides, and irrigation.

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(ii) An increase in the productivity of indirect energy inputs, especially water and fertilizers. There is a vast difference between the average and the best-practice efficiency of irrigation (Bos and Nugteren 1974). Large-scale canal irrigation in the tropics often involves vast evaporation and percolation losses even before the water reaches the farm. On the farm itself, the technique of water application has a considerable effect on its effectiveness. The underpricing of irrigation water in many developing countries encourages its inefficient use. Among fertilizers, the development of highly concentrated, water-soluble fertilizers (principally urea) has increased the efficiency of nitrogen uptake to 50 per cent or more. But the intake of phosphorus by the first crop is usually below 10 per cent, and of potassium, 20-40 per cent. Whilst the total uptake is higher because of phosphorus and potassium retention in the soil, considerable improvements in total fertilizer absorption are still possible (Food and Agriculture Organization 1978). Here again, the widespread subsidization of fertilizers can encourage their inefficient use.

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(iii) Increases in the efficiency of use of the indirect energy inputs, especially water, fertilizers and pesticides are closely dependent on the development of cultivars that can utilize them efficiently and on soil chemistry. Thus research on the three -- energy inputs, cultivars and soils -- should be closely coordinated.

Industry

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As pointed out in section III.4, industry offers considerable opportunities for interfuel substitution as well as energy conservation, and it is possible to exploit them relatively quickly and with little research because industries vary in energy intensity and it is easy to identify and concentrate efforts on the more energy-intensive industries (Anandalingam 1984). In fact, considerable research has

been done on energy use in the more energy-intensive industries such as steel, cement and fertilizers (see, e.g., Metals Society 1981; Mudahar and Hignett 1982; United Nations Industrial Development Organization 1985). The research on individual industries is too voluminous for the Group to have surveyed, and would be best utlized by each country or industry to suit its own interests.

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The usual approach to a policy on a national or sub-national scale is to start by energy audits of particular industries, to pinpoint those measures that would result in the most significant energy savings, and to devise policies to promote them. The measures are usually classified into three types (Tunnah 1984):

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(i) **Measures requiring major investments:** The technology of major energy-using industries has developed in energy-saving directions as energy prices have risen; plants of the latest vintage are considerably energy-efficient, for instance in steel, aluminium and cement. Thus the replacement of old plants by new ones can lead to considerable energy savings. More generally, the setting up of new plants which are likely to make a significant difference to a country's energy consumption needs to be looked at from a national point of view since the effect of the investment decision on energy consumption would persist for decades. Fiscal measures to promote energy efficiency, such as tax credits, investment allowances and accelerated depreciation, may be effective where there is competition and the economic prospects of an enterprise depend on its profits. But if monopolies or public enterprises are significant in the industrial structure, more direct regulation to promote energy efficiency may be necessary.

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(ii) **Measures requiring minor investments:** Whilst investment in more modern vintages of equipment for large, energy-intensive industries can save considerable energy, investment in small equipment for using and converting energy, such as motors and boilers, can have an equally significant impact on energy consumption where such equipment is used in large numbers. Equipment that can use waste heat also has a similarly large energy-saving potential. In the Group's view, both these types of equipment hold considerable promise in developing countries; they are therefore discussed in greater detail in section 4 below. Finally, better insulation and prevention of energy wastage generally require small amounts of investment in an individual plant but can make a significant difference overall. Opportunities for such small energy savings tend to get neglected; compared to large energy-saving investment for which fiscal and financial promotion measures are well developed, measures for small, heterogenous energy-saving investments are underdeveloped. This is an area where research could be of particular benefit to developing countries.

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(iii) **Housekeeping measures:** The very measurement of energy flows in an industrial plant, such as an energy audit involves, will suggest ways of increasing energy efficiency which require no investment, e.g., through adjustment of the excess air rate in furnaces, of temperature in chemical reactions, of loading rate in continuous processes.

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It would thus appear that a great deal of knowledge about energy use and conservation exists and more is continuously being generated in industry; what is required is not so much fresh research in developing countries but collection of information, its dissemination and its application to specific plants.

Transport

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Energy-related policies can be formulated at three levels in the field of transport: policies to reduce transport intensity of economic and social activities, policies to shift traffic to more energy-efficient forms of transport, and policies to increase the energy efficiency of vehicles, by increasing their size as well as by means of a shift from road to rail transport.

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(i) **Transport-intensity:** As shown in section III.5, there are enormous differences in the transport intensity of GDP across developing countries which suggest corresponding scope for its reduction in many cities. But not enough is known about its determinants to provide a solid basis for policy. It can be presumed that transport-intensity is determined by location patterns among other things, but precisely how they affect transport-intensity is not known. In this area, policy formulation would probably have to await definitive research.

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(ii) **Economies of vehicle size:** The rise in oil prices in recent years has generated great interest in increasing the energy efficiency of transport through the use of larger vehicles. In urban passenger transport, larger vehicles are undoubtedly more fuel efficient. Apart from this, public buses are clearly more accessible to the poor. However, developing countries, in the course of rising incomes, display the same shifts from public to private transport and from buses to personal vehicles as industrial countries. Such shifts take away the better-off passengers with a higher capacity to pay from public transport and contribute to its worsening financial viability. In the cities where public transport has survived and prospered, it has often been due to the growing inconvenience of urban driving; but it has also occasionally been due to the convenience, comfort and punctuality of public transport. Thus in the long run, the modal split between private and public transport is influenced less by price and more by quality of service. This fact offers scope for more sophisticated long-term urban passenger transport policies than have generally been attempted.

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Whilst large vehicles may be more energy-efficient, cities in developing countries are often characterized by small buses and other small means of public transport (Ocampo 1982). Clearly, energy costs are not an important determinant of the size of vehicles; other factors such as capital requirements, traffic flow characteristics, and ease of driving enter the picture. Energy efficiency is also affected by factors unrelated to size, such as the state of the roads, the level of congestion and traffic speed. Thus it is important that policies oriented towards increased energy efficiency should not be confined to the size variable but should take all the major influences in view.

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(iii) **Shift to rail transport:** The option of moving traffic from road to rail is attractive for two reasons: both because it increases energv efficiency and because it permits a shift from petroleum-based fuels to other fuels, principally electricity. However, the question of modal split between road and rail transport is altogether complicated. It is true that by and large railways require less energy per unit of transport. The reason is basically that rails entail less friction between the vehicle and the roadway than rubber-wheeled transport does. But less friction also means that at the same speed, a rail-borne vehicle would need a greater distance to stop (or to accelerate). If a rail-borne vehicle has to travel in congested conditions and in the midst of other traffic, as trams do, its advantage in terms of energy efficiency is reduced. Hence rail transport has bv and large survived where it has specialized in high-speed, relatively long-distance transport along dedicated tracks. Further, rail transport is more capital-intensive and requires high-density traffic to be competitive with road transport. Thus the spatial distibution of traffic density determines the boundary of competition between road and rail transport.

301n
However, in practice the division of traffic between road and rail is also influenced by their differing minimum scale. Roads can be widened and upgraded as traffic grows; and the investment in road vehicles required to maintain a minimum service is much lower than in railway rolling stock. Thus demand for transport is met by road transport facilities at low traffic densities, and continues to be so met as traffic density increases. When it increases to a point where a railway would be justified, the road transport system is already in place and its displacement is no longer economic. All the major railway systems of the world were built at a time when motorized road transport was nonexistent or in its infancy. Road transport grew

to maturity, most railway lines have been built where either the initial traffic density made railways the cheaper option (e.g., in the haulage of bulky ores from mines to smelters or ports) or where the traffic density grew so much that it could not be handled by road transport within the existing space limitations (e.g., urban commuter traffic).

302n

This is why, if transport facilities are left to respond to traffic needs as they arise, road transport is likely to gain a larger and rail transport a smaller share of the market than would be economically justified. To develop a viable railway system, it is necessary to forecast and plant the major traffic flows in a country for some decades in advance, and to make investments in railways in time to meet the growing demand. And even when timely investments are made in railway capacity, their utilization and hence the viability of railways depends crucially on three factors:

303n

(a) Traffic scheduling and communications on the railways: Because traffic moves about in trainloads, there is always a risk that wagons will be at a different place from where they are needed at any time. Moving them where there is demand requires the use of rail capacity which can be a bottleneck at junction points. Thus the scheduling of rolling stock and the utilization of track generate complex management problems.

304n

(b) Rate structure: As railways are regarded as a public utility, their rates are often subject to public regulation; and rate controls are used to cross-subsidize the transport of various products. However, when railways have to compete with road transport, they tend to lose highly rated traffic and hence the profits from which low-rated traffic is subsidized; this is a major reason why railways make losses. It is important that railway rate structures should bear a relationship to actual costs, and that if the railways are used to give freight or fare subsidies, such subsidies should come explicitly from the public funds.

305n

(c) Quality of service: The advantage offered by road transport relates to quality of service, speed and convenience. It is seldom enough for railways to offer lower freights or fares; they also have to offer comparable quality of service. To do so, they should be able and willing to offer both rail transport and the ancillary road transport required to carry goods from one point to another. Thus in order to be viable, railways need to be run as a joint road-rail enterprise offering integrated service.

Households

306n

In section III.6 we distinguished between three types of domestic consumers -- those who collected fuel, those who produced it and those who purchased it. It was also pointed out that those who collected fuel did not necessarily collect all other subsistence goods. From the viewpoint of policy it makes more sense to distinguish people on the basis of whether they collect, produce or buy food -- i.e., to distinguish between nomadic people, sedentary rural populations and urban consumers.

307n

It is virtually impossible to make effective policies for nomadic people. The only measures that are easy to enforce are those that restrict, regulate or influence their migrations. Measures to settle nomads in permanent villages, or to keep human populations out of reserved forests, for instance, are not uncommon. Such measures are not taken to deal primarily with energy problems, and are largely irrelevant to them. However, restrictions on the movement of firewood -- and indeed, all kinds of wood -- can be an important aspect of a policy to control deforestation.

308n
It is easier to formulate policies for settled and especially for agricultural populations. Agricultural taxation has been one of the mainstays of public finance in many developing countries. Even in agricultural economies that are not monetized, it is possible to have taxes or subsidies in kind. However, taxes or subsidies to influence the production or consumption of fuels or to stimulate interfuel substitution in rural areas are not common, apart from subsidies to rural electrification.

309n
Fiscal measures to influence urban demand for fuels, on the other hand, are very common. However, they are not focussed on households as such but on fuels they buy or on fuel-using devices. For that reason they are discussed in the next section and in section 4 below.

3. Resource-level Policies

310n
Policies affecting the prices of energy sources, especially oil products and electricity, are common in developing countries. Whilst they are not always instituted with demand management in view, their effects on demand are obvious; they are also often unintended and undesirable. More generally, the government influences prices through taxes and subsidies. But direct controls on prices are not uncommon, especially where the energv industries are publicly owned.

Taxes and subsidies

311n
The different energy sources, namelv oil products, electricity, coal and firewood, exhibit different market structures and hence offer different conditions for taxation and subsidization.

312n
Oil products are typically sold bv a small number of companies which extend their distribution activities all the way to the consumer, at least for transport fuels. Oil products are the joint products of refineries, so it is impossible to allocate production costs to them precisely. Hence there is much flexibility in pricing them. The only restriction on their relative prices is that the resulting demand pattern should not differ greatly from the pattern of supplies from the refineries. But refinery product patterns can be changed up to a point by making small and acceptable changes in the product specifications, and it is possible to change the patterns further by installing ancillary processes like cracking and visbreaking. It is also possible to balance the supply and demand patterns bv importing or exporting refined products. Hence considerable freedom of manoeuvre is available in fixing the relative prices of refined products, as well as in taxing or subsidizing them.

313m (p. 88, #3)
The way in which this freedom of manoeuvre is generally used is in the form of taxes on gasoline, on the grounds that it is used by rich car-owners, and subsidies on kerosene, on the grounds that it is used by the poor for lighting. Both have considerable substitution effects. Where the taxes on gasoline engines are high, the uses and development of gasoline engines are restricted. Gasoline engines can be miniaturized more than diesel engines and would be more widely used in small-scale applications, such as for irrigation pumps, if the price of gasoline were nearer to that of diesel oil. The development of diesel cars has been stimulated by lower taxes on diesel oil; insofar as they catch on, the progressiveness of the tax on gasoline is eroded. Here a better tax base than gasoline is available, namely cars; a shift of the tax from gasoline to cars would be better targetted on the rich and be more difficult to avoid.

314m (p. 89, #4) MM

The subsidization of kerosene leads to its use for less essential purposes, such as cooking, by those who are not so poor. It leads to the adulteration of diesel oil, for up to 20 per cent of kerosene can be mixed with diesel without noticeable side effects. It also prevents the emergence of alternatives to kerosene, such as electricity which gives light of a better quality. Unlike with gasoline, it would be impossible to make this subsidy more specific by shifting it to the user equipment, for the number of kerosene lamps is too large. It may be questioned if lighting by itself is a fit base for a subsidy to the poor. If it is held to be so, the impact can be made more specific to the poor by giving saleable rationing quotas giving them subsidized access (see section IV.1 above). Even so, a subsidy on kerosene will lead to its substitution for other forms of lighting; such a substitution effect can be removed only by giving a subsidy that is neutral between all illuminants (cf. Reddy 1978b).

315m (p. 98, #5) JG

The question may be asked whether a tax should not be levied on all oil products to encourage their replacement by renewable energy (Lovins 1977). The point of discriminating against nonrenewables is intergenerational equity: the more oil is consumed now, the less would be available to future generations. But the direct effect of a tax is not to transfer anything from one generation to a later one but to transfer purchasing power from the buyers of oil to the government in the same generation. Further, as we pointed out in Chapter I, the reduction of oil consumption by a developing country in one generation would do nothing to make more available to it later (except for oil within its own frontiers -- but that is an argument for importing oil instead of producing it). A differential tax on oil is therefore not justified on these grounds. The idea of a subsidy on renewables or on imported fuels may, however, have a stronger basis in particular national circumstances.

316n

Unlike oil products, the taxation of other energy sources is not widespread or systematic. Taxes on coal or electricity are not unknown, but their purpose is generally confined to revenue raising. Taxes on wood or charcoal are uncommon. Insofar as the burning of wood and coal generates considerable smoke and pollution, an opportunity is being missed here. Bulk fuels entering urban areas could easily be taxed at the city gate, and differential taxation of wood and coal could be used to encourage the use of charcoal and soft coke.

Pricing

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In many developing countries, the major energy-producing industries, namely coal, oil and electricity, are entirely or substantially state-owned. Even where they are not, their market structure often obliges the government to intervene in price formation. Thus pricing is the most actively used instrument of demand management in developing countries. However, the use of this instrument is commonly vitiated by average pricing based on historical costs.

318n

Among other things, average cost pricing gives the wrong incentives (or disincentives) to producers. Whether new resources should be exploited or new capacity created depends on the current marginal costs, not on average costs. Once the price ceases to be an indicator of investment requirements, other regulators of investment have to be brought in. Typically under diminishing returns or whether there is excess demand, average costs are below marginal costs, and prices set on the basis of average costs are too low to justify investment that would lead capacity to grow pari passu with demand. To persuade enterprises to make sufficient investment in the circumstances, governments introduce various investment incentives: for instance, low and stable interest rates, generous depreciation and investment allowances, and cross-subsidies for high-cost production. Each of these distorts the investment pattern in favour of the industries that are thus favoured, and within those industries, in favour of capital-intensive technologies and projects.

319n
The resulting discrimination works against new forms of energy which do not receive investment subsidies, but they are probably even more strongly disfavoured by another aspect of average cost pricing, namely transport cost averaging. Typically, large-scale energy forms such as coal, oil and electricity are sold at a uniform price over large areas irrespective of their transport costs. If their prices reflected transport costs, areas that were remote from their sources of supply would pay higher energy prices and would provide markets for alternative sources of energy whose costs exceed the average prices of large-scale energy sources but are below their delivered costs including transport charges.

320n
Amongst large-scale sources of energy, geographically uniform pricing favours those whose transport costs are low. Thus pricing practices probably contributed to the penetration of the markets for coal by oil. Conversely, if prices were made to reflect transport costs, energy markets would be less monopolized and a larger variety of energy sources would be able to hold market segments.

321n
Pricing based on historical costs leads to an imbalance between depreciation reserves and investment funds required for replacement. When equipment prices are rising, depreciation provisions fall short of replacement requirements; investment then needs incentives of the kind mentioned earlier. In the less common converse case, depreciation exceeds replacement requirements.

322n
Thus the need to get away from average cost pricing based on historical costs is evident in respect of energy. How precisely energy prices should be fixed is a complex area which attracts considerable research (Siddayao 1985); it is also an area where research can make a considerable difference to policy.

4. Energy Conservation

323n
The possibilities of energy saving are significant, and some of them are so easy to realize that official action to promote energy conservation holds attractions. Energy conservation measures are commonly focussed on industry because a small number of industries typically consumes large amounts of energy and offers scope for large energy savings, and also because the number of units in many industries is small enough for comprehensive coverage. But opportunities of energy saving are not confined to industry.

324n
Three approaches to energy conservation may be distinguished.

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(i) **Process improvement:** Scientific studv of energy-using processes can lead to significant energy savings. Industry-specific studies of this kind are not uncommon (cf. Moles 1984). But fundamental studies of energy-using processes applicable to a broad range of industries are rare. Research on combustion problems is probably the most widespread owing to the use of the process in industrial operations (Smoot and Hill 1983), but even in this intensively explored field, the gap between theorv and practice is wide (Weinberg 1975). The promotion and application of process research requires two things: first, a strong fundamental research capability in independent research institutions, and second, strong ties between the institutions and industry. It is possible for the government to promote both through financial and other incentives.

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(ii) **Investment in energy saving:** Such investment can range from incremental investment in insulation and waste heat recovery to investment in major new plants using energy-saving technologies. Techniques for incremental energy saving are fairly standardized and well known and do not call for much research. But their application will be encouraged by state action in surveying opportunities in various industries, as well as by subsidies to energv-saving materials and equipment. Saving

energy in new plants, however, is a part of industrial innovation, and will require the building up of industrial research capability as discussed in Chapter 2 above.

327n
(iii) **Efficiency improvement in user equipment:** This is a relatively new approach of considerable promise in developing countries. The manufacture of energy production equipment is still strongly localized in industrial countries. This is true of coal mining equipment, oil production equipment, and power plant, and may come to be true of solar and wind equipment also. This pattern of specialization will continue for some time at least. However, many types of user equipment are being used in very large numbers in developing countries, and quite a few -- such as motors, engines and batteries -- are being produced in the larger developing countries. Hence a strategy of concentrating on user equipment could lead to significant energy saving. A conservation strategy based on user equipment would deal differently with existing and with new equipment. Existing equipment can be surveyed in order to identify the major ways of saving energy, both by improving operational practices and by retrofitting such as replacement of valves and better insulation. Once the principal measures for saving energy are identified, they can be promoted by both persuasive means such as information dissemination, and coercive means such as the setting of minimum performance standards. The scope for the latter is greater in respect of new equipment. But in addition, research can be promoted to redesign new equipment for greater energy efficiency. The directions of such research are important from the policy-maker's point of view, and are indicated below for some important types of equipment.

Motors

328n
Motors are the prime device used to convert electricity into motive power, and are widely used for this purpose in all sectors except transport, where the portability and high energy content of liquid fuels make internal combustion engines the predominant prime mover. In stationary uses, the low cost, high energy efficiency and the wide range of sizes of motors give them an edge over internal combustion engines. In 1977, motors were estimated to account for 58 per cent of all electricity consumed in the United States and 45 per cent of the electricity used in motor drives was used in industry (United States Department of Energy 1980). Whilst comparable figures are not available for developing countries, electricity consumption in motors would be at least as significant in the countries where a large proportion of the electricity is used by industry; in addition, electricity is extensively used for irrigation pumping in a number of Asian countries.

329n
The energy efficiency of operations involving motors is a product of two factors, namely the efficiency of the motor itself and the proportion of the work done by the motor which is actually utilized. The efficiency of the motor itself is high for large sizes, but declines in the low horsepower ranges; in the United States, the efficiency of motors over 126 hp is estimated to be 87.5 per cent, but only 25 per cent in fractional horsepower motors (under 1 hp). This correlation of efficiency with size is inherent and would persist after improvements, but the possible proportional improvement is greater for small motors. However, 90 per cent of the 720 million motors in use in the USA are used in households; in developing countries where the level of domestic mechanization is lower, small motors are correspondingly less important. Although motors are a mature technology, with the advent of computer-aided design in the seventies, the efficiency implications of design changes could be modelled instead of having to be established from prototypes; hence technical improvements were speeded up. Even then, the maximum potential energy savings that would result if the current stock of motors were replaced by energy-efficient models was estimated to be 2.4 per cent in 1977 for the USA. The difference between the efficiency of the motors in stock and best-practice models is

probably greater for developing countries and needs to be surveyed in situ. But the general observation for industrial countries, that energy losses are much greater between the motor and the work done than within the motor itself, is likely to be valid for developing countries also.

330n

The energy losses in motor-driven work arise from the fact that the speed of a motor is fixed by the number of poles in it and the frequency of the electricity applied to it. In uses where variable speed is required, speed regulators such as gears, valves and throttles are used, and it is in these that most of the losses occur (Ladomatos et al. 1978). Three approaches to the reduction of these losses are available.

331n

(i) **Direct-current motors:** The speed of a dc motor can be varied by simple voltage regulation; the necessary voltage regulator can be quite cheap. However, dc motors are bulky, expensive and not always appropriate in industry. The commonest motor is the ac squirrel-cage induction motor -- cheap, simple and reliable. No simple way of regulating its speed is available as is with a dc motor (Ben Daniel and David 1970).

332n

(ii) **Conversion to hydraulic drive:** A variable range of speed and torque can also be obtained from hydraulic motors. This flexibility can be used to eliminate gearboxes on machine tools and to make them simpler and cheaper. The savings would be appreciable in a plant using a large number of machine tools, provided the entire plant was centrally supplied with hydraulic power. In a computer simulation of such a conversion it was also found that the energy efficiency of the plant would be raised from 54 to 68 per cent (Ladomatos 1979).

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(iii) **Variable-frequency drives:** These drives generally embody two devices in tandem or in combination: a rectifier to convert ac to dc current, and an inverter to provide adjustable three-phase voltages to the motor. They were pioneered in the synthetic fibre industry where the extrusion of the fibre requires precise and synchronized motor speed drives. Multi-motor drives are extensively used in the synthetic fibre industry. But variable-frequency drives have spread to other industries only slowly owing to high costs and lack of perceived need. Their wider application awaits a reduction in cost and miniaturization for use with individual motors. Application of microelectronics promises both, and has been the source of a number of design innovations in recent years (Mohan 1981).

334n

Of the three approaches, the last two are promising for developing countries. Conversion to hydraulics is worth considering only for entire plants, and only certain plants (e.g., machine tool plants) would be appropriate for it. However, opportunities for system applications of hydraulics are worth looking for in developing countries. The potential impact of variable-frequency drives is broader, but their development requires the application of microelectronics. For a country aiming for strength of the latter, design and development of variable-frequency drives would be an important step towards energy conservation.

Internal combustion engines

335n

An engine is primarily a machine for converting any of the different forms of energy into mechanical power and motion. Engines that convert heat energy into mechanical power and motion are called heat engines. Heat engines are classified as internal combustion engines (ICEs) or external combustion engines depending on whether the source of heat is inside or outside the engine. If the source is outside, then heat exchangers need to be used between the source and the sink of heat.

336n

Research and development activity in ICEs today seems to be directed primarily in the following three areas: (a) minimizing pollutant emission, (b) maximizing engine efficiency, and (c) maximizing engine tolerance to fuel types and exercizing greater control over the combustion process (Maly 1983). A distinguishing characteristic of these post-energy crisis research priorities is that they aim at total optimization unlike the earlier research on ICEs which was aimed at improving isolated subsystems, i.e., ignition control, turbocharging, knock control, etc.

337o (p. 162, #4)

Potentially the most promising area of research in ICEs is that of programmed combustion. In improving the overall combustion efficiency, efforts need to be directed towards decoupling the optimum conditions for ignition from those of flame propagation; this can be achieved by programming combustion in such a way that in-cylinder flow and turbulence are optimized. Two methods of doing this are to use purely electrical control or staged ignition. Attempts at controlling combustion have led to the development of the following IC engine designs:

338o (p. 162, #5)

(i) **Naturally aspirated divided chamber diesel engines** for light duty vehicles (most light duty vehicle engines are of this type now).

339o (p. 162, #6)

(ii) **Stratified charge divided chamber Otto engines** (these have found only limited applications).

340o (p. 162, #7)

(iii) **Rotary uniform charge Otto engines.** Early engines had serious problems with poor combustion chamber sealing, high hydrocarbon emissions and excessive engine misfiring under idling conditions, leading to poor driveability and lower fuel economy. They have been installed only in Mazda cars.

341o (p. 162, #8)

(iv) **Turbocharging** for both gasoline and diesel engines. Turbocharging has shown better results with diesel engines than with gasoline engines in terms of fuel economy, but in both cases it offers advantages in terms of lower CO and hydrocarbon emissions than the naturally aspirated versions. NO_x emissions, however, are higher (Dowdy 1983).

342o (p. 162, #9)

Advanced engines that have not been implemented on any production vehicle as yet and are still in research stages include:

343o (p. 162, #10)

(v) **Open-chamber stratified charge Otto engines:** The two major R&D programmes in this area are (a) the Texaco controlled combustion system, which not only aims at using lean air-fuel mixtures but also has the ability to use a variety of fuels as it is relatively insensitive to fuel properties, and (b) the Ford programmed combustion engine, which permits higher power output but makes the engine more sensitive to fuel properties (e.g., octane number). Yet another R&D approach in this area is referred to as the Mitsubishi combustion process, but little information is available about it.

344o (p. 163, #11)

(vi) **Rotary open-chamber stratified charge Otto engines:** These try to overcome the limitations of their nonstratified counterparts by attempting to increase the fuel economy and reducing the hydrocarbon emissions.

345o (p. 163, #12)

(vii) **Open-chamber diesel engines:** These attempt to improve combustion through enhanced air-fuel mixing and are classified by the magnitude of the swirl they develop in the combustion chamber (Cole et al. 1983).

346o (p. 163, #13)

(viii) **Adiabatic diesel engines:** In these engines an attempt is made to reduce the heat losses in the engine block and recovering the heat from the exhaust gases through the use of turbocompounding and/or a Rankine bottoming cycle. Even though these systems make the design of the engine much more complicated, they result in 25 percent less specific fuel consumption than in a large conventional turbocharged diesel engine. At present the research into adiabatic diesel engines is being sponsored by the US Army Tank-Automotive Research and Development Command (Dowdy 1983).

347n

Research on ICEs continues to be centred in the vehicle industries of industrial countries, and engine improvement has been an important component of comparative advantage in the international vehicle market in recent years. It is a promising area of research for developing countries with their own vehicle industries.

External combustion engines

348o (p. 163, #14)

The primary advantage of external combustion engines (ECEs) is that they can use a much wider variety of fuels than ICEs as the combustion chamber is separated from the moving parts of the engine. ECEs are basically of two types -- (a) Rankine cycle engines, and (b) Stirling engines. Rankine cycle engines can operate on any fluid that would undergo a phase change at a suitable temperature. They can be further subdivided into steam engines and organic Rankine cycle engines. The latter use an organic fluid (normally, Freon) as an alternative to water in the Rankine cycle.

349o (p. 164, #15)

The maximum working temperature of Freon-based organic Rankine cycle engines is about 150°C owing to the low boiling point of Freon. This low temperature reduces the maximum attainable efficiency (Carnot efficiency); for organic Rankine cycle engines of this kind, the best efficiency obtainable is about 10 per cent (Hurst 1984). Whilst the maximum attainable efficiency in Rankine cycle engines is limited by the temperature of the heat source and the heat sink, moving up to this efficiency essentially depends on achieving the best heat economies possible.

350o (p. 164, #16)

The basic principle of Stirling engines is that the pressure of air, or any gas, will increase if it is heated and decrease if it is cooled. The cylinder of a Stirling engine contains a certain amount of gas. In the early engines this gas was air but modern engines are more likely to use hydrogen or helium. This working gas contained in the engine is alternately heated and cooled. In each cycle, work is extracted from the gas in the form of the movement of a piston.

351o (p. 164, #17)

There are primarily two major directions of research in Stirling engines -- (a) free-piston Stirling engines and (b) Stirling engines for automobiles (Beale 1981; Dowdy 1983). Free-piston Stirling engines have the advantage that they are mechanically simple to construct and do away with critical seals needed otherwise to prevent the leakage of the working gas. They can be used as water pumps, cooling machines and as alternators to generate electricity. However, these engines have as yet remained only as demonstration units and research tools.

352o (p. 164, #18)

The Philips rhombic Stirling engine is currently the favourite for automotive applications. However, this high-pressure crank type engine has difficult sealing problems which have to be solved to avoid gas leakage and lubricant contamination of their heat exchangers.

Brayton cycle engines

353m (p. 161, #2)

Whilst the steam engine was the first to be developed, its bulk and inefficiency provided the impetus for exploring other engine principles. One such major engine principle was demonstrated in the 1870s in the Brayton cycle engine which used compressed air instead of steam to provide motive power. The nearly simultaneous development of Otto and Diesel engines (both ICEs) with greater power output per unit weight than the Brayton cycle engine made them the obvious choice as prime movers for vehicles. However, nearly half a century later with the development of better metals and greater knowledge of aerodynamics. Brayton cycle engines made a comeback but in a different form. Instead of pistons, they used rotary compressors and expanders (i.e., "turbines"), and such was their advantage in terms of power output per unit weight that they became the dominant prime movers for large-scale air transport.

354o (p. 165, #19)

Gas turbines are engines that work on the Brayton cycle principle, i.e., compression of a working fluid from ambient pressure to elevated pressure; addition

of heat to the working fluid at a constant elevated pressure; and expansion of the working fluid back to ambient pressure with the extraction of useful work. Like Stirling engines, Brayton cycle engines are continuous combustion engines but they can be either internal combustion engines or external combustion engines -- although the latter versions of the Brayton cycle engines have not been tried on any significant scale compared to the former.

355o (p. 165, #20)

Gas turbines are the most well developed of the Brayton cycle engines. For automotive applications two major types of gas turbines are being developed -- (a) single-shaft gas turbine, and (b) free-turbine gas turbine. Whilst the former requires the use of continuously variable transmission, the latter can use conventional automotive transmission. Given the high inlet temperatures in gas turbines, one of the most important areas of R&D activity is that of materials -- particularly ceramic materials for rotors and other structural elements (Dowdy 1983).

356m (p. 165, #21)

At present, external combustion or indirect firing Brayton cycle engines are in very early stages of development. The advantages of indirect firing are that the engine becomes less sensitive to the fuel quality and a number of low-grade fuels can be used (Rosa n.d.). Research on Brayton cycle engines in industrial countries remains focussed on vehicular uses; but research with a broader focus may yield significant results, especially for those developing countries that manufacture gas turbines.

Boilers

357o (p. 156, #1)

Boilers, both in industry and in power generation, account for a substantial consumption of energy. In the industrial sector, the share of boilers in energy consumption is determined by the importance of key steam-raising sectors, i.e., chemicals, engineering, food and paper. For OECD countries, for example, it has been estimated that boilers, on an average, account for about 40 per cent of the total industrial consumption of energy (International Energy Agency 1982). It would seem, therefore, that boilers are one of the most important areas for conservation of energy in both the developing and the industrial countries. In the immediate future, replacing oil by coal in boilers is likely to be an important area of concern for the coal-rich countries.

358o (p. 156, #2)

Conventional boilers: There are basically three types of conventional boilers -- sectional boilers, firetube or shell boilers, and watertube boilers. Sectional boilers are used in residential central heating, whilst the rest are used in industry.

359o (p. 156, #3)

Because the strength required to resist lateral bursting in firetube or shell boilers is directly proportional to the product of pressure and diameter of the shell, there are severe limits to the pressure that can be generated in these boilers. Normally, for steam pressure above 18 t/h, watertube boilers are used.

360o (p. 156, #4)

Firetube and watertube boilers may either be custom-made or package boilers. In the world's industrial boiler market, package boilers are the largest single sector and represent 75 per cent of the total order value. Their pressure rating is usually between 14 and 45 t/h and they use oil or gas as fuel (Dryden 1982).

361o (p. 157, #5)

In both firetube and watertube boilers, coal and oil present problems of excess air control in combustion. In the case of pulverized coal, the limits to the minimum amount of excess air are set by the conflicting demands of (a) the need to keep the combustion temperature below the fusion temperature of ash, (b) the need to avoid deposition of partially burned coal on wall tubes, which would cause corrosion by combustion in pockets of reducing atmosphere, and (c) the need to avoid excess air which might lead to condensation of exit gases and acid corrosion of gas passes. In the case of oil too, too little oxygen would present slack emission problems, and too

much of it would mean unacceptable corrosion rates. In the case of heavier fuel oils as of coal, there is a lower limit on exit-gas temperature and hence an upper limit on efficiency.

362o (p. 157, #6)

Conventional firetube and watertube type boilers also have problems with low-rank coal. Even though boilers can be designed for specific qualities of the coal being used, low-rank coals present operating problems by (a) fireside ash fouling of the boiler heat transfer surfaces, (b) their high variability with respect to moisture, sulphur and ash sodium concentration which create problems of maintaining unit capacity, and (c) making it difficult to control SO_x and NO_x (Goblirsch and Talty 1980). There is little in conventional boiler design or operation that can affect SO_x control; SO_x must be dealt with either before or after burning. NO_x emissions can be significantly influenced by boiler design and operating conditions, but the process of NO_x creation during coal combustion remains a little explored area.

363o (p. 157, #7)

Given these limitations, the major objective of research in the area of conventional boilers, especially those being used in power plants, is likely to be that of improving the heat rate. The two future trends in this area are likely to be (a) the introduction of on-line performance monitoring systems at more plants to pinpoint deteriorating components and areas of efficiency loss, and (b) the use of on-line diagnostic monitoring tools to anticipate failures, schedule outages, order spare parts and provide manpower in an optimal manner (Yeager 1984).

364o (p. 158, #8)

Fluidized bed boilers: Fluidized bed boilers were designed to overcome a number of problems associated with conventional boilers. In these boilers, the fuel is burnt on a bed of turbulent air. This improves the combustion efficiency; and if limestone or dolomite is added to the fuel mixture, sulphur can also be removed. The temperature of combustion is also relatively lower in fluidized bed combustion. Although research on fluidized bed combustion began as early as 1944, till the early seventies it was being conducted in a climate of dwindling interest in coal. It gathered pace after the oil crisis (Patterson and Griffin 1978).

365o (p. 158, #9)

Fluidized bed boilers have four basic advantages over conventional boilers -- (a) different fuels can be burnt in the same combustion unit, (b) desulphurisation of flue gases requires little technological effort, (c) NO_x emissions are lower because combustion takes place at lower temperatures, and (d) high heat release and heat transfer coefficients can drastically reduce boiler size, weight and cost (University of Oklahoma 1975; Howard 1979; Poersch and Zabeschek 1980). The implication is that fluidized bed boilers can be built as factory-assembled, packaged units, shipped to sites and arrayed as required. If this happens, there could be a considerable reduction in the construction times of new power plants. However, standard product lines of fluidized bed boilers have not been developed as yet.

366o (p. 158, #10)

Fluidized bed boilers can be of two types -- atmospheric boilers and pressurized boilers. The latter combines a gas turbine and a steam turbine cycle, which increases the overall efficiency of the system by approximately 5 per cent (Muller et al. 1982).

367o (p. 159, #11)

Poor combustion efficiency and high particulate emissions arising from short residence time of the fuel in bed, poor lateral mixing and the high elutriation of fine particles of carbon sorbent or bed, and difficulties in removal of ash and heavy combustibles have led to R&D on "circulating" bed fluidized bed boilers. These boilers are characterized by nonuniform fluidizing velocities, secondary air flow over the bed, a sloping distributor plate, in-bed fuel injection, deflector walls and membrane walls. Liquid fuel can also be used in these boilers without an atomizer (Tata Energy Research Institute 1983). It is these boilers that have a greater chance of commercialization in the future than conventional fluidized bed boilers.

368o (p. 159, #12)
Retrofitting existing boilers: One of the major problems which is encountered in retrofitting existing boilers to coal or biomass fuels is that of derating of capacity. Also, existing boilers which use oil and gas often cannot easily be retrofitted to direct coal or biomass combustion because large new combustion chambers would be required for direct firing. However, charcoal-oil slurry can be burnt with only small modifications in existing equipment (Meta Systems 1982). Conversion to coal firing is easier than changing over to biomass firing. In the latter case, an alternative could be to utilize low or medium heating value gas obtained from gasifiers.

369o (p. 159, #13)
In retrofitting oil and gas fired boilers to coal or introducing new coal fired boilers, the economics is site-specific. The most favourable case may be that of a greenfield site where expenditure on a new boiler must be incurred and where there are no constraints imposed by a layout of an existing site. The next most favourable case could be of an existing site where an oil or gas boiler needs replacement because it has reached the end of its life. And lastly, there could be cases where economics is sufficiently favourable to take an oil or gas boiler out of service early and replace it with coal (International Energy Agency 1982).

370o (p. 160, #14)
However, efficient retrofitting can be done only if countrywise boiler stock records are created, listing characteristics such as the number of boilers and installations, pressure specification of the steam required, capacity distribution of the boilers, age distribution, utilization and hence the fuel requirement, tvpe of fuel currently used and previous conversion of fuel usage. Only on the basis of this information can the site-specific economics of retrofitting to coal in each country or regions within it be worked out. An inventory of national boiler stocks would therefore be the first step in any research in this field.

Solid fuel stoves

371o (p. 153, #1)
One of the few valid generalizations that emerge from rural energy surveys is that in developing-country households with working women, women are cooks, and are extremely busy -- generally busier than men. Saving time on cooking does have value to them. Every cooking operation has an optimum heat input: a lower rate of heat supply will slow down the operation, a higher rate will waste energy. The reason for the high energy efficiency of cooking with gas or kerosene is that both allow extremely precise control of heat output; this is also the reason why they are preferred by cooks everywhere.

372o (p. 153, #2)
The way in which heat output is controlled in fluid-fuel stoves is through the control of fuel supply -- by means of a valve in a gas stove, and by the regulation of wick length in a kerosene stove. The valve or the wickholder effectively separates the combustion zone from the fuel tank. This separation cannot be achieved in the case of a solid fuel. The combustion zone is a part of the fuel; and every fuel has a characteristic time pattern of heat supply. For instance, in a fuel with high moisture content the water will first be vaporized; heat supply during this phase will be low. As the water is driven out, heat supply will increase. Fuels with a high surface-to-volume ratio like straw, dungcake or paper will burn and begin to supply heat rapidly; fuels with a low ratio like hard coal will burn slowly.

373o (p. 153, #3)
Every cook learns or works out ways of making the recalcitrant solid fuels yield her required heat demand pattern. First, she mixes slow-burning and fast-burning fuels: for instance, she starts the fire with a quick-starting fuel like straw, and uses thick logs when she wants a slow fire. Second, she withdraws fuel from the combustion zone; sticks and logs are particularly easy to pull out or push in. Third, she quenches the fire when she does not need it or when she wants to

reduce heat supply. Finally, she uses different cooking devices -- a fast-burning waterheater with a chimney for bath water, a small iron charcoal-burning stove for small but quick jobs like making tea, a massive earthen stove for long cooking jobs, etc. All these are time-saving devices; those of them will be used which the cook can afford with the given income and fuel supply. For instance, in an area where only fast-burning fuels like straw and dung are available, the cook will make foods that can be cooked quickly; in households which are short of fuels hot baths will be uncommon, and so on.

374o (p. 154, #4)

The inefficiency of fuel use in cooking arises from (a) the characteristics of the various solid fuels and (b) the degree of mismatch, given the fuels and the tasks, between the heat supply and demand patterns. Thus efficiency varies enormously from situation to situation. Inefficiency of cooking is a casual observation that has been overgeneralized; there are considerable variations in the achievable increases in fuel efficiency (Foley and Moss 1983; Manibog 1984).

375o (p. 154, #5)

The approach to fuel efficiency in research may be briefly described as follows. Overall efficiency is a product of (i) the proportion of the energy in a fuel that is available, (ii) the proportion of available heat that reaches the pot, and (iii) the proportion of the heat reaching the pot that is absorbed into the food. Of the three, the first is uncontrollable; research has concentrated on the second.

376o (p. 154, #6)

There have been three major approaches: (a) the use of a chimney or of flow geometry to accelerate air flows and to ensure more complete combustion; (b) a baffle or other device to control air inflow; and (c) waste heat storage in water, stove walls, etc. Each approach works with some fuels and in some cooking tasks and not all. Acceleration of combustion is unwelcome in tasks where slow heat is required. Baffles are ineffective with fast-burning fuels like straw which draw air through the pothole. Waste heat storage is useless and might in fact reduce fuel efficiency if the cooking is completed quickly. Every innovation is mismatched with some common fuel or cooking task; hence it shows a confusing variation in field performance.

377o (p. 155, #8)

It is obvious but true that a household will not be interested in fuel-saving unless fuel is scarce or expensive for it. The first requirement is to identify markets where fuel pinches people. From the research that has been done, it appears that urban populations that depend on wood or charcoal meet this specification.

378o (p. 155, #9)

It is also likely that efficient stoves will be fuel-specific. Wood and charcoal are the candidate fuels. Of these charcoal is more transportable, less polluting, and easier to standardize. So we have stressed the need in section VII.2 to develop techniques of producing cheap, high-quality charcoal.

379o (p. 155, #10)

Finally, the two obvious ways of increasing fuel efficiency are by increasing the volume and improving the insulation. Both are easier in the case of large, commercial stoves. The incentive to save fuel is also greater, or more obvious, in the case of commercial activities like restaurants. So greater and quicker success may be obtained by turning to the requirements of large, commercial users.

380o (p. 155, #11)

Research need not stop there, but it must begin by identifying the markets for innovations by studying the fuels used by households and their cooking tasks. It is likely that such a study would lead to a variety of optimum stoves specific to a range of fuels and tasks (Caceres 1985).

D

V. LIQUID FUELS

381o (p. 86, #1)

The parallel development of liquid fuels and internal combustion engines has led to a situation where the two together dominate road transport all over the world. If a changeover to other fuels were to become necessary, it would save considerable investment in user equipment if substitute fuels could be used in existing vehicular engines. Even if they required modified IC engines, the existing engine-making facilities could be used to make them.

382e

IC engines can use a broad variety of liquid and gaseous fuels, all of which would be potential substitutes for gasoline and diesel oil. Their competitive strength would depend on three factors: (a) their cost of production, (b) their cost of delivery and handling, and the attendant convenience and risks, and (c) their effect on vehicle efficiency and costs. The following conclusions would seem to embody the best guess on the relative prospects of oil substitutes.

383m

(i) Oil will not run out suddenly, and its supply is unlikely to show a sudden fall; rather, its cost will rise and its quality will decline progressively, though not continuously, making oil substitutes and oil-saving technologies competitive, and leading to a shift from oil to other energy sources (Odell 1984).

384m CS

(ii) However, the oil market is characterized by oligopolies on both the supply and the demand side; hence the oil price is inherently unstable and unpredictable (Hartshorn 1982; Turner 1983; Bohi 1983; Adelman 1985). This instability would lead many countries that can do so to seek some security in high-cost substitutes for international oil, namely domestic oil, or oil substitutes. Such import substitution or oil substitution is likely to appeal more to countries which spend a high proportion of their exchange receipts on oil, and amongst them to those that are not covered by the IEA-centred oil security arrangements, which extend only to industrial countries.

385m CS

(iii) Industrial countries use oil on such a large scale that a substitute for it cannot be biomass-based (Smil 1983). It will come to be based on gas or coal. Technologies to produce vehicular fuels from coal are well known and have been updated in the seventies. But the investment costs of gas-based fuels are lower and gas-based plants are more reliable in operation. Hence the first substitutes in industrial countries are likely to be gas-based -- compressed natural gas (CNG), liquefied petroleum gas (LPG), methanol and gasoline from gas.

386o (p. 87, #7)

(iv) When brought into use, gas-based fuels and technologies will be available to developing countries also. But substitutes based on biomass that grow easily in the tropics are of special interest to them. Ethanol is the most promising of these; but methanol could be equally promising if low-pressure, low-temperature technologies were developed for it. Both of them will be of greater interest to countries with difficult balance-of-payments situations.

1. Oil

387o (p. 187, #3)

The rise in oil prices in 1973-74 and again in 1979-80 had such a drastic impact on developing countries that it came to be regarded as the major energy-related problem. Developing countries as a group are extremely oil-dependent. If China and India, both major coal producers, are excluded, 61 per cent of the commercial energy consumed by the rest in 1980 was provided by oil (World Bank 1983a). For some of the energy importers, the high cost of oil has led to a squeeze on nonenergy imports, heavy debt burdens resulting from borrowings, and domestic deflation forced by pressures to repay the debts. In Table 7 we list the

TABLE 7

Energy imports as a proportion of exports and foreign exchange receipts, 1981[a]

($ million)

Country	1 Energy imports	2 Merchandise exports	3 Exchange receipts[b]	4 1 as a percentage of 3	5 1 as a percentage of 2
Brazil	12049.4	23276.0	10340.0	116.5	51.8
Guatemala	749.2	1299.0	974.9	81.5	61.1
Ivory Coast	543.1	2734.0	819.6	66.3	19.9
Turkey	3903.5	4703.0	5937.0	65.7	83.0
Kenya	720.7	1072.0	1161.1	62.1	67.2
Trinidad	1192.0	2531.0	2030.7	58.7	47.1
India	6531.8	8437.0	11450.0	57.0	77.4
Morocco	1121.0	2283.0	2001.0	56.0	49.1
Nicaragua	216.9	500.0	408.3	53.1	43.4
Jamaica	496.7	974.0	959.9	51.7	51.0
Uruguay	534.6	1229.7	1130.7	47.3	43.5
Thailand	2974.7	6902.0	6362.0	46.8	43.1
Philippines	2574.9	5722.0	5653.0	45.5	45.0
Dominican Republic	475.2	1188.0	1045.8	45.4	40.0
Liberia	127.4	529.0	291.0	43.8	24.1
Ethiopia	164.6	374.0	379.7	43.3	44.0
Republic of Korea	7864.0	20671.0	19653.0	40.0	38.0
Sri Lanka	466.2	1062.5	1250.8	37.3	43.9
Tanzania	283.0	688.3	760.0	37.2	41.1
El Salvador	213.8	768.0	648.0	33.0	26.8
Pakistan	1497.6	2730.0	4737.0	31.6	54.9
Costa Rica	203.3	1003.0	681.9	29.8	20.3
Sudan	289.5	792.7	1002.4	28.9	36.5
Colombia	797.5	3219.0	2868.0	27.8	24.8
Chile[c]	963.6	4705.0	3498.0	27.5	20.5
Jordan	739.3	733.2	2776.1	26.6	100.8
Tunisia	684.8	2102.0	2685.0	25.5	32.6

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[a] Only countries for which energy imports as a percentage of foreign exchange receipts was greater than 25%.

[b] Foreign exchange receipts were calculated by totalling (i) merchandise exports, (ii) other goods and services (net credits) and (iii) unrequited transfers (private and official).

[c] 1980 figures.

Source: Compiled from World Bank (1982b; 1983b; 1984) and IMF (1984).

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developing countries for which the burden of energy imports is the heaviest. There can be some debate on how to measure the burden. It would be simplest to relate energy imports to merchandise exports. But for some countries, invisible receipts have become important in recent years: receipts from tourism in the case of some, remittances from emigrants for others. On the other hand, invisible payments -- principally interest payments -- have created difficulties for other countries even when the balance of trade was favourable. Hence we have related the energy imports to merchandise exports as well as to all major receipts on the current account.

388o (p. 187, #4)

Some oil exporters face the obverse problem of excessive dependence on oil. The rise in the value of oil exports leads to the appreciation of the domestic currency, the decline of domestic industry and the growing specialization of the country's activity base. The danger is greater when the reserve-production ratio is low and oil is expected to run out in the near future: in those circumstances, it is difficult to restructure the economy fast enough to ensure that there is no fall in per capita income when oil runs out. To identify such countries we give the export dependence on oil and the reserve-production ratio of those developing countries that rely heavily on oil exports (Table 8).

389n

Solutions to the problems arising from oil dependence can be sought at different levels of generality. All countries can tackle them by means of macroeconomic planning (see section II.1 above). They can also look for solutions through energy demand management (section IV.1). They can explore the economic viability of producing oil substitutes, principally ethanol and methanol, which are discussed in the succeeding sections. Finally, they can look for oil within their own frontiers and produce it. And those countries that produce or import it can refine it. These options are discussed below.

Exploration and development

390o (p. 90, #6)

Exploration and production were relatively mature technologies in the sixties. The advent of offshore drilling and deep drilling, whose competitiveness was greatly increased by the rise in oil prices, has made exploration and production technologies into rapidly changing frontier technologies. With this acceleration of technological change there has been a change in the technology market. Earlier oil companies, especially the major ones, had better mastery of technology than others outside the oil industry. In the last 15 years the technology market has tended to divide up into a number of specialist technology markets, each dominated by a few specialist firms (Surrey and Chesshire 1984).

391o (p. 90, #7)

The major multinational oil producers are no longer the prime owners or controllers of technology. But they still possess field experience which is important in interpreting and dealing with site-specific geological conditions; and they have competence in packaging the bits of technology from specialist companies as required for particular exploration or development jobs.

392m CS

In the sixties, the major oil companies supplied oil to the market economies from a small number of prolific fields. Owing to the low cost of production from those fields it was difficult for newcomers to compete with them; the oil market was therefore oligopolistic and stable. However, the leases of oil companies in West Asia and North Africa were nationalized in the early seventies; the major oil companies were converted from owners into marketers of oil. They therefore became more interested in exploring new areas. The appropriation of their profits by the oil producing countries reduced the competitive strength of the majors and made it easier for newcomers to enter. Thus there developed a market in exploration and production contracts in the seventies. The norm was for a country to lease out blocks for exploration. Both the attraction of bids and the drawing up of contracts became skilled operations. The expertise they require has been available from professional consultants or through technical assistance programmes of the United Nations agencies. This has also been an area of some good studies (e.g., Hossain

Country	1 Exports of petroleum and products 1981 (US $m)	2 Exports of all commodities 1981 (US $m)	3 Energy exports as a percentage of total merchandise exports (1/2)	4 Estimated proved reserves of oil 1.1.1983 (m bbl)	5 Estimated oil production 1982 (1000 b/d)	6 Reserve-production ratio (years) (4/5 x 365)
Libya	15 513	15 571	99.6	21 500	1 127	52.3
Iraq[a]	10 914	11 064	98.6	41 000	914	122.9
Saudi Arabia	116 222	119 916	96.9	162 400	6 484	68.6
Iran[b]	250 555	25 943	96.6	55 308	1 896	79.9
Nigeria[c]	15 563	16 405	94.9	16 750	1 324	34.7
United Arab[a] Emirates	8 585	9 078	94.6	n.a.	n.a.	n.a.
Oman	4 420	4 696	94.1	1 730	328	22.8
Venezuela	16 265	17 518	92.8	21 500	1 826	32.3
Algeria[d]	14 313	15 624	91.6	9 440	750	34.5
Qatar	4 920	5 389	91.3	3 425	340	27.6
Trinidad and Tobago[d]	3 378	3 761	89.8	580	182	8.7
Congo[d]	856	955	89.6	1 550	87	48.8
Gabon	1 925	2 189	87.9	460	130	9.7
Kuwait	13 178	16 300	80.8	64 230	675	260.7
Syria[d]	1 662	2 108	78.9	15 210	175	23.8
Mexico	13 910	19 379	71.8	48 300	27 340	48.4
Indonesia	14 393	22 260	64.7	9 550	13 410	19.5
Egypt	2 082	3 232	64.4	3 325	667	13.7
Brunei	2 413	4 022	60.0	1	155	21.9
Ecuador[c]	1 178	2 104	56.0	1 400	215	17.8
Tunisia	1 352	2 504	54.0	1 860	106	48.1

[a] 1978 figures
[b] 1977 figures
[c] 1979 figures
[d] 1980 figures

Source: United Nations (1984), McCaslin (1983).

1979; Van Meurs 1981). Exploration contracts require a complex combination of law and economics, and oil contracts have much in common with other resource contracts. There will continue to be need for research in this area for the application of principles to new situations and for systematization of experience.

393o (p. 91, #9)

However, it is not clear that all developing countries need to do is to devise the right terms of contract. For oil companies require a combination of low political risk and high economic returns that few developing countries can offer (Parra 1983). Of the major expansions of oil production since 1973, two -- in North Sea and Prudhoe Bay -- have been in industrial countries, and one in Mexico, which is contiguous to the United States. It is particularly difficult for those developing countries which, either because of large domestic markets or small discoveries, are unlikely to become substantial exporters, to attract oil companies.

394m CS

Statistics from the IED-EDPRA database are revealing (Table 9). Between 1973 and 1981, concessions in producing developing countries remained roughly constant, whilst those in nonproducing developing countries fell drastically. Seismic work nearly doubled in producing countries and declined in nonproducing countries. And of the 678 exploratory wells drilled in developing countries, only 40 were in nonproducing developing countries. Thus exploration activity is highly concentrated in countries where prospects have already been proved and have resulted in production. And most of the exploration activity in producing countries is not by multinational oil companies at all; over 70% of it is by national oil companies of Argentina, Brazil and India (Foster 1985).

TABLE 9

Indicators of exploration activity in oil-importing developing countries

		Producing	Nonproducing	Total
Contractual holdings of prospecting rights, m km^2	1973	1.58	5.92	7.50
	1980	1.57	2.55	4.12
	1981	1.53	2.87	4.40
Seismic work, thousand line-km	1973	125.1	86.6	211.7
	1980	237.9	60.4	298.4
Exploratory wells drilled, number	1983	638[a]	40	678[a]

[a] Data exclude India and are probably incomplete for some other countries.

Source: Derived from Foster (1985).

395o (p. 93, #11)
Thus there are indications of market failure here: it is possible that small or politically "risky" oil prospects in developing countries are underexplored for of companies that would package and sell the required services. The framework for filling this institutional gap exists in the Caracas Programme of Action (Dorado 1985), and a number of constructive ideas have been generated by Peter Ross (1984) in his paper written for the Group. We consider this a highly promising area for research and action.

Refining

396o (p. 93, #12)
Only a few developing countries have a large enough domestic demand for refined products to justify their own refineries. A lasting surplus in world refining capacity, arising largely from new and efficient refineries set up by oil-surplus countries, is forecast (Fesharaki and Isaak 1983). Hence refining margins will be low for years to come, and the incentive to replace refined product imports by crude imports for domestic refining will be weak. However, crude transport is easier and cheaper than transport of refined products, so big countries which refine imported crude will continue to do so.

397o (p. 93, 13)
Thus the rate of investment in refining is likely to be low for years to come. However, opportunities for improvement lie in two fields. First, fuel efficiency and capacity utilization can be improved. Second, refinery operations can be adjusted to tailor output to the demand pattern. A number of processes are available for this purpose, such as hydrocracking, catalytic cracking, and coking. Choice among the processes, can be the subject of site-specific research (Bhatia 1983; Shaw et al. 1983; Lipuma et al. 1983).

2. Alcohols

398m (p. 94, #1) AR
Among liquid substitutes of oil products, two alcohols, methanol and ethanol, are the most likely candidates. Their energy density is appreciably lower than that of oil-based fuels (Table 10). Hence larger quantities of them would be required to drive the same distance, and the same volume in the storage tank of a vehicle would give lower mileage. But as their high octane number implies, they can be used as straight fuels in engines with higher compression ratios, and can achieve higher fuel efficiency than their energy content would suggest; pure ethanol is thus expected to achieve 20 per cent higher efficiency in a high-compression engine than its energy content implies (World Bank 1980). Both are highly soluble in water and therefore difficult to separate from it. Whilst some water can be tolerated in them if they are used alone, they must be anhydrous if blended in gasoline.

399o (p. 94, #2)
Despite these limitations, they would be serious candidates for substitution as vehicular fuels if oil became significantly more expensive. The reason is that being liquids, they are cheaper to handle and transport than solid or gaseous fuels. Petroleum fuels have dominated road transport despite the fact that natural gas was much cheaper per unit energy in North America; part of the reason is that the delivery system was built up for liquid fuels and fed into a large stock of oil-driven vehicles. It was impossible for gas to break into the market because the entry costs were very high. If oil were to become more expensive, it would be easier for alcohols to take over a part of the market than for gaseous fuels.

400o (p. 94, #3)
Methanol is already in use in the manufacture of high-octane gasoline additives. Both methanol and ethanol improve the octane rating of gasoline if added in small quantities (about 4-6%), and are preferable to lead additives or alternative refining processes for this purpose. This is the best use of alcohols in vehicular

Table 10. Main physical/chemical properties of methanol, ethanol, and hydrocarbon fuels

Property	Methanol	Ethanol	Gasoline	Diesel	Fuel Oil
Chemical Formula	CH_3OH	CH_3CH_2OH	C_4 to C_{12} Hydrocarbons	C_{14} to C_{19} Hydrocarbons	C_{20} + Hydrocarbons
Specific Gravity	0 79	0 79	0 72-0 78	0 83-0 88	0 88-0 98
Composition (weight %)					
Carbon	37 5	52 2	85-88	85-88	85-88
Hydrogen	12.5	13 1	12-15	12-15	12-15
Oxygen	50 0	34 7	negl	negl	negl
Stochiometric Air/Fuel Ratio a/	6.5 to 1	9 to 1	14.5 to 1	14 5 to 1	14 5 to 1
Heat of Combustion b/ (Btu/lb)	8,570	11,500	18,900	18,300	17,200
Latent Heat of Evaporation c/ (Btu/lb)	506	392	150	110	
Boiling Temp C°	65	78	27-225	240-360	360+
Flash Point C° d/	11	13	-43	38	66
Autoignition Temperature C° e/	470	423	425-510	260	-
Flammability Limits in Air (volume %)	6 0-36 5	3 3-19 0	1 4-7 6		
Octane Number f/					
Research (RON)	106-115	106-111	79-98	not appl	not appl
Motor (MON)	82-92	89-100	71-90	not appl	not appl.
Blended RON(BRON) g/	115-145	110-135	not appl	not appl	not appl.
Blended MON(BMON) g/	88-120	90-115	not appl	not appl	not appl
Cetane Number h/	negl	0-5	5-10	45-55	not appl
Solubility in Water	infinite	infinite	0	0	0

a/ Air/fuel ratio required for the combustion of the fuel

b/ Heat released in the combustion, also referred to below as energy content or calorific content The figures are based on the lower heating values

c/ Heat required to vaporize the fuel

d/ Minimum temperature at which the fuel will ignite in the presence of a flame.

e/ Minimum temperature at which the fuel will autoignite in the absence of a flame

f/ The octane number measures a fuel's ability to burn smoothly, i e , without knocking, in a spark-ignition engine The higher the octane number, the higher the feasible engine compression ratio and hence engine efficiency

g/ The octane-boosting effects of alcohols in blends, i e , their so-called blending octane number values, tend to exceed their laboratory octane numbers by an amount which depends very much on the composition of the base gasoline to which they are added

h/ The cetane number measures a fuel's characteristics with respect to spontaneous ignition in a compression-ignition (diesel) engine

Source: World Bank (1982a).

fuels, and is economically justified even now in particular circumstances. They can be used in higher proportion (15-20%) as extenders to blend with gasoline without engine modification. In this use what matters is whether their costs are lower than those of gasoline; foreign exchange shortage may justify their shadow pricing in local conditions. If they are found cheaper or economically justifiable, the designing of engines to use them without blending would also be justified as long as the demand was large enough.

Methanol

401e (p. 96, #4) AR

Methanol has long been in use as a solvent and an intermediate for acetic acid and other chemicals, and continues to be a bulk chemical. It is mainly produced from naphtha or natural gas. Its producibility from natural gas is what makes it a prime candidate for gasoline substitution. For if industrial countries need a substitute it will be required in very large quantities, and a biomass-based substitute cannot be produced in sufficiently large volumes without devoting a large area of agricultural land to its production (Smil 1983). Such substitutes will appeal to countries with a large arable area per capita, and may become more viable as the efficiency of use of liquid fuels rises. But for industrial countries as a group, methanol from natural gas would remain of considerable interest.

402o (p. 96, #5)

The currently dominant process of synthesis gas conversion is a high-pressure, high-temperature process. Its capital costs are high, and economies of scale are significant up to single-train capacities of 2000-2500 tpd or 0.6-0.75 mtpy (Humphreys 1977). So a country would have to consume 3-4 mtpy of gasoline to consider producing methanol for blending. If the methanol were to be used undiluted in specially designed engines, a country would have to import methanol-driven cars and hence await their commercialization elsewhere -- or manufacture and commercialize them. Thus either way, only a country with a large domestic demand for gasoline can take initiative in methanol substitution. This limits the possibilities to perhaps half a dozen of the larger developing countries (or combinations of smaller countries).

403m (p. 97, #6) AR

Methanol can also be produced by gasification of wood, and was in fact so produced till the advent of cheaper hydrocarbon feedstocks. This technology is being modernized (Reed 1981; Egnéus and Ellegård 1985). It is also possible that advances in enzymatic hydrolysis will improve the performance of wood as a feedstock for ethanol, which is a better automotive fuel (Ostrovski et al. 1985; Saida 1985). However, collection of wood from large enough areas to support a methanol plant is costly, and wood has valuable alternative uses as timber and in paper industries. So whilst experimentation in wood-based methanol continues, it seems unlikely that it will compete internationally with gas-based methanol. Thus closer, site-specific investigation of process options would be necessary before major investments in methanol research can be recommended; they are likely to prove feasible where the shadow price of foreign exchange is high.

Ethanol

404m (p. 97, #7)

There are few developing countries yet which have natural gas but have not found oil, and fewer among those whose balance of payments is so difficult that they must consider methanol as a gasoline substitute. Except for those few, ethanol has better prospects than methanol. There is an established process for its manufacture from biomass; it is a fermentation process in which economies of scale taper off at a much lower level than in the case of methanol. There do not seem to be pronounced economies of scale above the level of 240000 lpd (≈ 200 tpd) that is normal for new

distilleries in Brazil. The process is based on the one for rum manufacture, which has been used and is well understood in many developing countries (Rolz et al. 1983). Whilst rum and ethanol manufacture are confined to cane-growing countries, fermentation of other feedstocks is carried on in many developing countries, and sugar-rich crops appropriate for ethanol manufacture -- principally maize, sweet sorghum and cassava -- can be grown under many agrarian conditions.

405m (p. 98, #7) JG

The economics of ethanol as a vehicular fuel is marginally favourable in Brazil, where it was initially commercialized under subsidy (Goldemberg et al. 1984; Kahane 1985). Elsewhere there are less favourable indications (cf. Koide et al. 1982). But a production base exists for ethanol in Brazil; elsewhere too it is being produced for use in beverages and chemicals. Hence there is considerable scope for process experimentation, for which a number of promising directions are indicated. Below are the major ones.

406o (p. 98, #8)

(i) **Reduction of feedstock costs:** Since feedstock is the single major item of cost, a reduction in its cost would improve the economics of alcohol significantly. A major component is the cost of feedstock transport; it can be reduced by increasing cane yields, on which research is being concentrated in Brazil.

407o (p. 98, #9)

(ii) **Increasing plant capacity utilization:** Sugarcane is a seasonal crop which can feed a plant six months in the year at best; the more the season is extended, the lower the sugar recovery, and the greater the danger of disease and fire. A number of ways of improving capacity utilization have been proposed. One is the chipping and drying of cane for use throughout the year, as in the EX-FERM process (Jenkins et al. 1982). Another is concentration and storage of cane juice. A third is a combination of cane and sorghum as feedstocks (Instituto de Pesquisas Tecnologicas 1981).

408o (p. 98, #10)

(iii) **Process improvements:** Advances in fermentation chemistry are leading to ideas for more efficient fermenters involving cell immobilization (Tokuyama 1984) and packed bed reactors (de Cabrera et al. 1982).

VI. GASEOUS FUELS

409o (p. 99, #1)

As a fuel, gases (all of which are mixtures of methane with other gases) have the advantage over solid fuels that they are free of particulates. Being fluids, they are also easy to handle. But like solid fuels they have a low energy density. Being airmiscible they also require airtight containers and transport facilities. Both these factors make them expensive to transport.

410o (p. 99, #2)

Being hydrocarbons, gases have the chemical versatility of oil. Most petrochemicals can be made from gases, and usually with lower capital costs than from oil. They can also be used in internal combustion engines; in view of the limited range of application of liquid substitutes for oil-based vehicular fuels, gases may find large-scale uses here as well. Thus gases are in many ways the natural successors of oil. But their high transport costs will lead them to be used nearer their production sites than is the case with oil; and when transported they will tend to travel in larger volumes over fewer routes. Oil was and is the great decentralizer of mechanized industry and transport; the dispersal of industry into less developed areas was more rapid in the era of cheap oil than ever before. This trend is likely to be reversed if oil becomes expensive and is replaced by gas, coal and electricity.

1. Natural Gas

411m MM

Natural gas is a generic term for naturally occurring methane, higher paraffins and nonhydrocarbon gas. Methane is the principal component; ethane, propane and butane are the other hydrocarbon gases. Under pressure, gas also contains dissolved alkanes such as pentane, hexane and heptane. But they liquefy at atmospheric pressure and can be separated when gas is produced.

412o (p. 100, #2)

Most of the gas discovered hitherto has been found as an accidental byproduct of oil exploration. There is no exploration for gas as such, and exploration techniques specific to gas have not been developed. Seismic techniques are not effective in discovering gas, and unless techniques are developed, the discovery of gasfields will continue to suffer from greater uncertainty than that of oil.

413o (p. 100, #3)

Despite this absence of systematic exploration, discovered reserves of gas have risen rapidly in the seventies to 3261 EJ and are approaching the proved reserves of oil (3892 EJ) (Ion 1984a). The rate of exploitation of gas reserves is, of course, much lower than that of oil, and a high proportion of associated gas continues to be flared. The usability of gas depends on the costs of collecting and transporting it to a processing plant. Where oil is being won out of a large number of small wells, collection costs of associated gas are high often too high to justify collection. Nonassociated gas in large fields can often be exploited more economically (Schramm 1984).

Occurrence

409m

The conditions of gas formation are broader than those of oil: there are three known modes of gas formation and an inferred one (Tiratsoo 1979).

415o (p. 101, #5)

(i) **Marine-origin gas:** The marine kerogens derived from the bacterial breakdown of marine algae and plankton are the raw materials for petroleum formation. Thermal degradation of the kerogens at temperatures between 60°C and 150°C leads to formation the process through thermal cracking: wet gas is often found associated with oil. At temperatures over 150°C, however, methane is likely to be the chief product. It is thus likely to be often embedded in deep sedimentary basins (Grunau 1983).

416o (p. 101, #6)

(ii) **Coal-related gas:** The coalification of peat and lignite involves the generation of methane. The total methane so generated dwarfs the coal reserves of the world. Most of it escaped into the atmosphere or was dissolved in water, but much was retained in coal and forms a nuisance in the mining of gassy coal; some accumulated in traps after migrating from coal, and can be exploited.

412o (p. 101, #7)

(iii) **Biogenic gas:** Methane is generated by anaerobic microorganisms during the decomposition of organic matter. This occurs naturally in tropical marshes; hence the term "swamp gas". Most of the gas is vented into the atmosphere, but some gas can be dissolved in water and buried in sediments. Biogenic gas constitutes about 20 per cent of the world's gas reserves.

413o (p. 101, #8)

(iv) **Abiogenic gas:** Though there are no significant accumulations, there is some support for gas of abiogenic origin, generated perhaps by the out-gassing of carbon-containing meteorites incorporated in the mantle and upper crust when the earth was first formed.

414o (p. 102, #9)

Thus it is likely that gas can be found in many formations unrelated to oil. Exploration for gas thus deserves to be an important part of resource exploration programmes in developing countries.

Uses

415o (p. 102, #10)

Historically, gas has generally been burnt as it came from the ground. But nowadays it is worthwhile separating its constituents if the gas production is large enough. As stated earlier, the energy density of gas is low, and the transport costs are consequently high. However, the energy density can be increased by compression, and even more by liquefaction. Liquefaction requires a lowering of the temperature, and the greater the reduction required, the greater the energy required to liquefy and to maintain the liquid phase.

416e (p. 102, #11) JG

Of the gases, propane, iso-butane and n-butane have relatively high boiling points (Table 11). It is common to liquefy and bottle them. The resulting liquefied petroleum gas (LPG) is a popular domestic fuel. It is preferred because of its smokeless flame and its controllability, which makes it possible to match minute by minute the requirement and supply, and raises the fuel efficiency associated with its use. LPG can also be easily used as a vehicular fuel. Taxis and even cars are fueled by LPG in many developing countries, notably Pakistan, and Republic of Korea.

417o (p. 102, #12)

Methane requires more energy to liquefy and more expensive handling and transport in liquid phase. Hence it is liquefied only if the volumes to be handled are large. The principal markets for liquefied natural gas (LNG) have been in industrial countries, and developing countries have considered LNG plants largely for export. Whilst a number of large export-oriented LNG plants are on stream or under construction in developing countries, the market in industrial countries is competitive and limited, and a country would need very large and highly accessible gasfields to enter this market (Mashayekhi 1983).

TABLE 11

Paraffins found in natural gases

	B.pt. at atmospheric pressure	
Methane CH_4	- 161.5°C	gaseous at N.T.P.
Ethane C_2H_6	- 88.5°C	
Propane C_3H_8	- 42.2°C	
Iso-butane C_4H_{10}	- 12.1°C	
n-Butane C_4H_{10}	- 0.5°C	
Iso-pentane C_5H_{12}	27.9°C	liquid at N.T.P.
n-Pentane C_5H_{12}	36.1°C	
n-Hexane C_6H_{14}	69.0°C	
n-Heptane C_7H_{16}	98.4°C	

Source: Tiratsoo (1979).

423o (p. 104, #13)

Short of liquefying methane, the best that can be done is to compress it. The containers for compressed gas at 2400 psi must be strong and therefore heavy, and even with compression they give a vehicle only one-third the range of oil. They thus call for more refilling stations. Refilling also takes longer, up to 10 minutes (West and Brown 1979). Nevertheless, 250 000 vehicles use it in northern Italy. Conversion of large trucks and buses to gas would be especially economical in the vicinity of gas fields (Economic and Social Commission for Asia and the Pacific 1984; Mortimer 1984).

424o (p. 104, #14)

Finally, the cheapest means of transporting methane is in pipelines, which offer enormous economies of scale. Hence the major use for piped methane is in large industries: principally fertilizers, chemicals and power. But in concentrated urban centres, commercial and residential use may also justify pipeline supply (Mashayekhi 1985).

425o (p. 104, #15)

Thus the size and location of gas reserves as well as the domestic and foreign markets of a country will indicate an optimum marketing pattern, whose determination requires site-specific research.

2. Biogas

426m (p. 105, #1)

In principle, biogasification is an extremely versatile process to convert low-grade biomass into a low-calorie fuel. In practice it is a sensitive technology which calls for skill in operation, like producer gas technology. However, whilst a gasifier needs a mechanic to set it right, a digester needs a chemist. Since chemists are not nearly so ubiquitous as mechanics, digesters that malfunction are set right less often than mechanical devices.

427o (p. 105, #2)

It has been the subject of considerable experimentation in developing countries (Brown and Tata 1984). It is also one of the most widely adopted renewable energy technologies in developing countries. But compared to the geographical range of experimentation, the range of application is extremely limited.

428o (p. 105, #3)

Biogasification has been adopted on a mass scale only in China and India; and in both countries there seems to be considerable geographical concentration: application has been largely confined to areas where there are a large number of stabled animals -- pigs in China and cattle in India. Apparently it is not enough that large supplies of animal residues should be available; it is equally necessary that the labour costs of collection should be low. Even if animals are grazed by otherwise unoccupied children, carrying the daily household requirements of 50-75 kg would be onerous. If rural people are unlikely to expend labour on collecting animal residues, large animal populations will not be a sufficient condition for biogas propagation; it is likely to remain confined to farm families with a sufficient fodder output to maintain stabled animals. This would considerably narrow the limits of application of biogas -- unless there was a shift in rural areas from grazing to stabling. Thus the promise of biogas appears to be related to changes in agrarian systems.

429o (p. 106, #4)

The most common scale in developing countries is small, but gasification, being a volumetric chemical process, is subject to economies of scale. Larger plants have been built for urban municipalities in developing countries and for large cattle farms in industrial countries. The size of plant appears to have been determined by the size of the farm enterprise. The application of the technology to specialist dairying enterprises in developing countries, both large and small, is unexplored. However it is also true that the operation of biogas technology is still uncertain and the failure rate of biogas plants is fairly high. It would have to work much more reliably before it can be readily adopted by commercial enterprises.

430o (p. 106, #5)

Apart from collection costs, the major costs are the capital costs of the digester, and research has sought to reduce them in two ways: by reducing the construction or fabrication costs (cf. Stuckey 1983), and by accelerating the throughput of substrates and increasing gas ouput (Advisory Committee on Technology Innovation 1977). Attempts to reduce fabrication costs are common in developing countries; they mostly involve changes in design or in materials. In industrial countris, on the other hand, the biogas ouput is of secondary importance, and biogasification is generally used to biodegrade farm and industrial effluents and to render them innocuous. Hence the accent has been on maximizing throughput of substrate and accelerating the reactions (Klass 1982).

431o (p. 106, #6)

However, this direction of research has relevance to developing countries also since acceleration of throughput and of reactions also incidentally raises the gas output. The focus of research in developing countries may be different, but the following ideas that recur in industrial country research are promising in a developing-country context:

432o (p. 106,#7)

(i) The first stage of hydrolysis does not require anaerobic conditions and can be carried out outside the digester in ambient conditions.

433o (p. 107, #8)

(ii) This suggests a two-stage process in which acidogenesis is carried out in the first container, and methanogenesis in the second; reaction conditions can be optimized separately in each.

434o (p. 107, #9)

(iii) Microorganic activity determines the retention times in both stages and hence plant productivity. Cell immobilization techniques make it possible to increase it, to observe it, to grow microorganisms outside and to introduce them into plants.

435o (p. 107, #10)

Thus advances in the knowledge of the chemistry of biogasification make chemical experimentation promising; this is a direction that could be followed more intensively in developing countries.

3. Producer Gas

436o (p. 108, #1)

Producer gas is a low-calorie mixture of carbon monoxide, methane and noncombustible gases (mainlv nitrogen and carbon dioxide) obtained by partial combustion of carbonaceous materials. Its technology dates back almost 200 years. The Otto engine was invented almost a hundred years ago to use producer motive power, but later came to be run almost exclusively on gasoline. But whenever there was a shortage of gasoline, producer gas has been revived. The peak was probably reached in World War II, when the Allied blockage led to serious shortages of oil in Europe and Japan; 900 000 vehicles were estimated to be using producer gas in 1942. However, it was virtually unknown even then as an automotive fuel in North America, which had ample oil. In the era of the cheap oil that followed, producer gas nearly died out. Despite considerable interest from researchers, producer gas failed to revive in any significant way when oil prices rose in the seventies. Gasifiers are being manufactured and used in Brazil and the Philippines, but account for an insignificant proportion of energy output; elsewhere, whilst engineering firms have made prototypes in the hope of developing a market, gasifiers have only been objects of research and experimentation (Foley and Barnard 1982).

437o (p. 108, #2)

The reason appears to be that the operation of gasifiers is much more labour-intensive and troublesome than of oil engines. Oil engines can run unattended for hours. Gasifiers require more attention and supervision. The quality of attention can affect their operation significantly, and inattention can be costly in terms of breakdowns. In particular, there are four ingredients of biomass fuels which can do great damage unless carefully monitored and controlled; namely

(i) **tars:** if they get into the engine it will malfunction and may have to be opened up for cleaning;

(ii) **ash:** noncombustible mineral matter can lead to slagging and clinkering if it is allowed to accumulate; and

(iii) **particulates:** these too must not get into the engine if it is to work well.

(iv) **moisture:** in addition, if green wood is burnt, the steam entering the gas affects engine performance and can lead to corrosion.

438o (p. 109, #7)

These ingredients are inherent to biomass fuels, and the problems they generate can only be anticipated and minimized, not eliminated. Standardization of the fuel (e.g., use of charcoal) can remove some problems and make others more predictable; given the fuel, the design can be adapted so as to minimize the problems connected with that fuel. But to the best of our knowledge, troublefree, stand-alone operation has not been demonstrated for gasifiers under any conditions.

439o (p. 109, #8)

The considerable research on gasifiers has focussed on two objectives: saving of oil and minimizing the derating of the engine that attends the use of gas (cf Beijer Institute 1983). The object of reducing the labour-intensity and the skill-intensity has not been taken seriously; it has been assumed that labour is or should be treated as being cheap in developing countries. But even where labour is cheap, skill often is not; and if the cost of skill is measured in terms of gasifier breakdowns it prevents, it may be unobtainable in many places.

440o (p. 109, #9)

All the problems gasifiers suffer from have well established technical solutions. Producer gas was produced from coal and piped to residences in Britain until natural gas took over in the late sixties. The large gasifiers then in use embodied devices to tackle all the problems generated by the feedstock. It is not that the solutions to the problems are unknown; rather, they are uneconomic in the small gasifiers that are supposed to be appropriate for developing countries.

441m (p. 110, #10) AR

Hence research on gasifiers probably needs to move in two directions, namely (i) standardization of the fuel, and (ii) exploitation of economies of scale, which would make gas-cleaning devices economical.

4. Hydrogen

442n ZYJ

The knowledge of hydrogen gas is traced back to Paracelsus, who obtained it by reacting iron with sulphuric acid, and established its combustibility (Aureille 1984). In the modern world hydrogen is an important chemical intermediate used to make ammonia for nitrogen fertilizers, in hydro treatment of mineral oil and in the manufacture of methanol.

443n ZYJ

It attracted widespread interest after the rise in oil prices in the early seventies for a number of reasons. First, it can be readily used as an engine fuel, and can thus replace oil products in vehicles without extensive reequipment. Second, it can be made from water, whose available stocks are enormous. Third, its combustion yields water, its potential raw material; it can thus be infinitely recycled. And finally, its combustion is nonpulluting and can thus avoid the environmental ill-effects of fossil fuel combustion. Its combustion in air would generate nitrogen oxides, but not those of sulphur; nor would it generate carbon dioxide, whose effects on global temperature are a source of concern.

444n ZYJ

The fact that hydrogen is being produced in bulk for chemical uses makes it easily available for experimentation. Its advantage over fossil fuels in respect of environmental effects makes it interesting to the electrical power industry, and its potential as an engine fuel makes it attractive to the transport equipment industry, concerned as it is with the rising costs of oil products. In addition, hydrogen has been used as a reactant in alkaline fuel cell power plants on board U.S. and French spaceships (Srinivasan 1984; Doniat and Rouget 1984). Thus the interest of potential users with large resources for R&D has made hydrogen energy one of the most active areas of energy research in the past decade. It has evoked interest in Brazil, China and India among developing countries (Campos 1984; Mattos 1985; Li et al. 1984; Nema et al. 1984).

445n ZYJ

However, there is a broad agreement among students of the question that hydrogen will be uncompetitive with substitute fuels for some decades at least. The cheapest way to produce hydrogen at present is by steam reformation of hydrocarbons; the ones commonly used are natural gas (methane and propane), refinery gases and naphtha. Hydrogen produced by this process will be inevitably more expensive than the hydrocarbons from which it is made. Thus it cannot compete with petroleum liquid fuels now, and when these become expensive, hydrogen from steam reforming will not be able to compete with natural gas, which can be used as easily as hydrogen in engines and, is cheaper to transport since methane, its major component, has four times the energy density of hydrogen (Gelin and Petit 1980; Fein 1982, 1985). Hydrogen is cheaper than electricity in the United States even now, but cannot capture any of the markets for electricity owing to lower end-use efficiency and greater difficulty of transporting it (Gaines and Wolsky 1984).

446n ZYJ

Thus hydrogen is unlikely to emerge as a competitive fuel as long as oil or gas is the dominant energy form -- except perhaps in small special markets like steel-making. When the cost of oil and gas increases, they will be replaced by coal, with which a number of liquid and gaseous fuels (including hydrogen) can be made. Among them, synthetic oil and methanol would be more convenient as transport fuels. Being liquid fuels with higher energy density they would be cheaper to store and transport; and such cost calculations as have been made suggest that they would be cheaper too.

447n ZYJ

Thus hydrogen may not emerge as a competitive fuel until coal extraction costs rise considerably -- which, in view of the large world reserves of coal, may be some centuries away. But hydrogen's competitiveness would improve much earlier if definite signs of environmental deterioration led industrial countries to restrain fossil fuel consumption. As we discuss in Chapter XI below, there is considerable controversy on whether and when this will happen; there is also considerable variation in opinions about how much environmental deterioration is tolerable. But if and when public opinion turns against fossil fuels as strongly as it did against nuclear power in some industrial countries in the seventies, the prospects of hydrogen as an alternative fuel will improve.

448n ZYJ

When that happens, hydrogen would not be produced from fossil fuels even if the costs of production were low, for hydrogen production by that means would be as environmentally undesirable as any other combustive use of fossil fuels. It would thus have to be produced from water; and all processes for doing this require large amounts of energy (Bockris 1985; Ohta et al. 1985). Hence to be competitive, hydrogen would need an abundant and cheap source of energy. Three have been suggested: nuclear power, off-peak electricity and solar energy.

449n ZYJ

Nuclear power can in theory be produced in abundance, especially if breeder power reactors are commercialized. It has the advantage that in addition to electricity, such reactors produce considerable waste heat which can be used to increase the energy efficiency of electrolysis. If coal-based power generation is phased down for environmental reasons and nuclear generation is not, nuclear power would clearly be the prime potential source of hydrogen.

450n ZYJ

If either nuclear or hydroelectric pwoer is used to make hydrogen, the question of its uses would become important. Basically, two have been proposed:

451n ZYJ

(i) **Hydrogen as an energy carrier:** It may be produced in off-peak hours. It may also be generated in regions with surplus power and transported by pipeline to power plants where there is excess demand for power. Electricity generated from hydrogen will inevitably be more expensive than the electricity that produced it, both because of conversion losses and production costs; whether it is still economical or not would depend on the difference in the cost of off-peak and peak power. Technoeconomic research on this question is sparse. It suggests the following: (i) building excess capacity in reservoir and hydroelectric generation capacity is likely to be cheaper than hydrogen production; (ii) hydrogen makes better sense where it can be used directly; (iii) if excess generator capacity turns out to be more expensive or is ruled out, hydrogen storage is likely to be cheaper than alternative storage techniques, and (iv) hydrogen storage is better for long-term energy storage, e.g., from one season to another; for short-term storage, in the range of a day to a week, batteries or pumped storage may turn out to be cheaper (Carpetis 1984; Fein 1984). However, there are a large number of alternatives and parameters in such calculations, and site-specific research is necessary to test the viability of hydrogen storage.

452n ZYJ

Hydrogen transport is cheaper than the transport of energy-equivalent electricity, but its actual economics will depend a great deal on the distances involved and on whether hydrogen has a direct use at the distination. The cost of alternative fuels at the destination will determine the competitiveness of transporting hydrogen as well as electricity. Here, as with storage, only site-specific investigations can determine the viablity of hydrogen transport. But clearly, the first countries for such investigations are those that have abundant hydropower resources in remote locations, such as Brazil, Canada and China.

453n ZYJ

(ii) **Hydrogen as a transport fuel:** If electricity and electricy-based hydrogen come to be the major energy sources, it is likely that hydrogen, though more expensive than electricity in terms of delivered energy, will nevertheless command a substantial part of the market for transport energy. The reason is that if transport is as personalized and vehicles so numerous as they are now in industrial, and indeed

in many developing countries, electricity cannot be conveyed to so many vehicles by means of transmission lines, as it is done in electric trains; it must be stored in batteries on board the vehicle. Batteries are heavy and impose a penalty on energy consumption. It can be reduced, though not eliminated, by more frequent charging of vehicles. In a city with a well-developed transmission network this would pose no problem; it would be enough to have a large number of power outlets where vehicles are usually parked. But charging of batteries takes time, so there will be an upper limit on the proportion of time a vehicle can be driven, and on how long it can be driven without charging. In uses where such limits are unacceptable, hydrogen will be the only admissible fuel. Among vehicles where such limits cannot be placed are buses, trucks for interurban transport, ships -- and aircraft. So the market for transport (other than rail transport) would be divided up, relatively small and short-haul vehicles being powered by electricity and large and long-haul vehicles being powered by hydrogen.

454n ZYJ

Research on hydrogen energy is an area of considerable activity and extreme volatility; it is not possible at this stage to narrow down the lines of research to a promising few. If, as stated earlier, it will be at least a few decades before hydrogen finds a significant market as a fuel, there is no urgency about hydrogen research. It may have greater relevance to the small number of countries with favourable hydroelectric sites, poor fossil fuel reserves and difficult balances of payments.

VII. SOLID FUELS

455o (p. 111, #1)

Solid fuels were the major source of energy till the turn of the century. Biomass was the main source till the industrial revolution. Then demand for energy grew so much and became so geographically concentrated that biomass could not supply it and mineral coal gained in use. In the 20th century oil gained over solid fuels for three reasons. First, unlike coal which had to be mined, oil was brought to the surface by subterranean pressure. Thus under the favourable initial conditions under which it was found, it was cheaper. Second, it had a higher energy density. In terms of weight it had almost 1.5 times the energy density of best coal; in terms of volume it was even better. Hence its transport costs were lower. And finally, it was well suited for use in internal combustion engines. As a result it became the main means of motive power, especially in vehicles. Only a part of the oil can be refined into products that can be used in engines; this proportion can be increased only by highly capital-intensive methods. So the products that could not be used in engines -- the residual fuel oils -- were used directly as fuel and competed with solid fuels.

456o (p. 111, #2)

With the rise in the price of oil, innovation in industrial countries concentrated on reducing the oil demand for prime movers. This considerably slowed down the growth of demand for gasoline and diesel oil, and hence the growth of supply of its joint product, fuel oil, and has led to the growth of demand for coal as a heating fuel. It is likely that this process will continue worldwide. The demand for engine fuels will determine the supply of fuel oil, whose price will be such as to find a market for it. Fuel oil price will determine the maximum price of coal, and the output of coal will be what can be produced at that price.

457o (p. 112, #3)

The prospects of the developing countries that wish to enter the international market for coal will be governed by this international mechanism (Wilson 1977; Greene and Gallagher 1980; Long 1982; Gordon 1984). Those countries that are using their coal domestically may price it above international levels if they are under balance of payments pressure, and increase its domestic use. This applies as well to countries with good prospects for firewood production.

458o (p. 112, #4)

It is unlikely, however, that solid fuels will find a significant use as engine fuel even in these countries. They can be so used only by conversion into producer gas. On the prospects of producer gas from biomass we have commented in section VI.3. Coal gasification faces similar problems if done on a small scale. Besides, in small-scale use producer gas would compete with electricity. Electricity is generally cheaper than even diesel power once transmission facilities are in place. Thus our assessment of the prospects of small-scale producer gas does not change if mineral coal is considered as the fuel instead of biomass.

459e (p. 112, #5) JG

On a large scale, coal-based producer gas has two potential markets: for domestic and commercial use and for power generation. It would find a domestic or commercial use in urban areas near coalfields. But most of them are being served by soft coke (for instance, in north China and eastern India). Where coking coal is available, it is unlikely that producer gas can compete with it. And in power generation the currently used steam turbines do not face potential competition from producer gas. Thus whilst the technology of coal-based producer gas is well established and can be further improved, its application will depend on what markets can be found for it.

460o (p. 113, #6)

An exception may be producer gas from underground coal gasification. In principle, this technology has tremendous scope. Millions of tons of coal have been discovered in the course of exploration for oil that are too deep to mine at competitive costs at present; even at much higher energy prices they would be difficult or impossible to mine.

461o (p. 113, #7)
Underground gasification is the only possible use for them in the near future. Considerable experimentation is going on with it in industrial countries. But the results are most unpredictable (Schilling et al. 1981). We have not been able to make a dependable assessment of it.

462m (p. 113, #8)
Another technology we have left out of judgment is magnetohydrodynamics. In principle, MHD can increase the efficiency of power generation considerably. Unlike underground gasification, it is known to work. But the operational MHD plants -- all of them small ones -- are in the USSR, and what we have been able to discover second hand does not justify a confident assessment.

1. Coal

463o (p. 114, #1)
The coal industries of industrial countries, which were the prime source of energy till the advent of oil, steadily lost ground to oil after World War II and were weakened by competition. In their years of decline their rate of investment was low, and so was their rate of innovation. Most of the innovations came from equipment manufacturers, but mining enterprises contributed to it by defining the site-specific conditions for which the equipment was required. The equipment markets were and are largely national, and because innovations are site-specific, they are not necessarily transferable to developing countries. Hence coal-producing developing countries need to acquire informed buyer competence in the first place and capacity for adaptive innovation in the second. These are the areas in which research and the buildup of research competence need to be concentrated (Surrey and Chesshire 1984).

Mining technology

464o (p. 114, #2)
Coal, iron ore and bauxite are the three most important bulk minerals of the world. All were initially discovered near the surface. Surface reserves of iron ore and bauxite are so large that all their mining is above ground; they are served by a large surface quarrying equipment industry. This industry has continuously innovated and scaled up its products to give higher throughputs and lower costs. Quarrying equipment has been adapted to coal, and technical progress in it has given an edge to surface mining of coal over underground mining. In all countries where both were available, surface coal has gained ground over underground coal; underground coal has come increasingly to be exploited with open cast techniques after overburden removal.

465o (p. 115, #3)
However, the old coal-producing countries, Britain, France and Federal Republic of Germany, have no significant surface deposits. Faced with competition from oil and US coal, the underground coal mining industries of the three countries developed longwall mining techniques to increase productivity and reduce capital costs (Peng and Chiang 1984). In the USA with its more abundant and shallower reserves, machines were developed for room-and-pillar mining (Meyers 1983).

466o (p. 115, #4)
China and India have the largest and oldest coal mining industries amongst developing countries. Both employ relatively labour-intensive techniques; and since overburden removal by manual means is too expensive, both have traditionally had predominantly underground mining. However, the throughput of labour-intensive mines is low. Consequently labour-intensive techniques require a larger number of mines, with their requisite fixed investment in shafts and haulages, per unit of output; and since shaft and gallery construction are time-consuming, the rate at which output can be raised is constrained. Hence both the countries have been turning towards surface mining.

467o (p. 115, #5)

However, both China and India have large underground coal mining industries which need to be mechanized if capital costs are to be reduced and a rapid growth of output is to be maintained. Both have imported longwall technology and machinery and are in the process of indigenizing them. However, their coal is at shallower depths than in Europe, and India also has thick and multiple seams. Roof support during extraction and sublevel caving after it raise problems under these conditions. Powered supports developed in Europe are not always effective, and roof collapse after extraction is not even (Sarkar 1980; Mathur 1980; Sarkar et al. 1983; British Mining Consultants 1983a, 1983b). These problems are site-specific, and require user-learning which comes through the development of technological competence in the users and close interaction between them and the equipment manufacturers. There is also scope for learning from experience -- especially from the mutual experience of China and India.

468o (p. 116, #6)

Other developing countries which have begun to mine coal more recently, such as Colombia, invariably employ mechanized surface mining techniques. At high levels of mechanization, both above and below ground, capacity utilization has a decisive influence on the economics of the industry. This has two important aspects. One is equipment maintenance. This is generally an area of weakness in developing countries; a high level of competence in maintenance can form the basis of interaction between the mining enterprise and the equipment manufacturer, and lead to innnovation. The second and related aspect is operator and management training. Labour-intensive mining employs large numbers of unskilled workers and tends to have rather simple, authoritarian management structures. Mechanized mining, on the other hand, requires better trained workers with mechanical experience and aptitude, and works better if they are given more initiative. The necessary change in the style of management does not come easily to old-established mining enterprises, but is nevertheless essential for new technologies to be effective. Interpretation of experience through research can in these circumstances mediate between old managements and new technologies.

Transportation

469o (p. 116, #7)

Transportation is generally more mechanized than mining, but here too the mechanization of mining requires the raising of the throughput of haulages, handling facilities and transport equipment (Surrev and Chesshire 1984). It thus raises the same types of maintenance and training requirements as mine mechanization.

470o (p. 116, #8)

Often coal from a mine is exclusively dedicated to use in a single power plant or other user, and generates a large volume of transport in a single direction with no return loads. When a common carrier like railways is used for coal transport, this type of traffic leads to low fleet utilization and makes traffic scheduling difficult. Railway traffic studies are of great importance where bottlenecks are being faced or are in the offing. But it is also necessary to explore other modes of transport. In particular, coal slurry transport is feasible, presents technical problems that are soluble, and can be commercialized with an input of research. The water requirements of coal slurry are large and must be met at the minehead; the coal must be dewatered at the destination and the water disposed of without causing pollution. The design of the pipeline system would also be different from that of gas or oil pipelines: the pumping stations would have to be spaced more closely, the conditions of keeping coal in suspension would need to be established. Nevertheless, these problems pose a manageable research assignment (Grainger and Gibson 1981).

Coal preparation

471o (p. 117, #9)

All coal contains noncombustible mineral matter -- ash -- in varying proportions. Ash reduces the energy density of coal; in addition, it reduces the output of coal-burning equipment such as furnaces, boilers and blast furnaces. For these uses it is often economic to reduce the proportion of ash in coal even at some cost if this reduces the downstream costs. Coal preparation, as the reduction of ash content is generally known, can be done in four ways. Manual techniques are useful only for low throughputs and are not always reliable. Mechanical techniques can be employed for large outputs, but are even less discriminating. Magnetic techniques can be used with a limited range of impurities. All three are ineffective where the carbonic and mineral elements are strongly bonded. Where they are, chemical flotation is the most effective. In India as well as China washeries employ chemical flotation agents in water, but a number of new techniques have been tried or suggested: for instance bulk oil flotation, selective flocculation, electrostatic separation and ionization processes for sulphur removal. Thus coal preparation offers opportunities for fruitful research in the form of a well-defined problem and a range of possible solutions (Zimmerman 1982).

2. Charcoal

472m (p. 118, #1) JG

Charcoal has an extremely high proportion of carbon, and was the only reducing agent and fuel used in ironmaking before the industrial revolution. The growing demand for iron led to deforestation in Britain, and the search for an alternative to charcoal led to mineral coal in the eighteenth century. The use of charcoal in iron smelting has been revived in Brazil and Argentina; in Brazil it is used to produce about 10 mt/y of steel. It holds considerable promise for countries with a large biomass potential. Elsewhere, the enormous quantities involved as well as the larger blast furnaces permitted by the use of coke will ensure the use of mineral coal at least while coking coal lasts.

473o (p. 118, #2)

Charcoal powder also has a high surface-to-volume ratio, and was used as active carbon in chemical reactions before the advent of petroleum coke. Petroleum coke is a byproduct of oil refining and will be priced so as to sell whatever is produced. Hence charcoal is unlikely to be able to compete with it. But if a slowdown in the total demand for oil leads to a shortage of petroleum coke, charcoal will undoubtedly be a serious alternative.

474o (p. 118, #3)

Charcoal continues to be used in large quantities as domestic fuel in some developing countries, especially in the cities of Southeast Asia and Africa. Here and elsewhere, it faces competition from LPG, kerosene and electricity. These fuels enter the upper-income markets first because of their convenience, and are increasingly adopted at lower income levels as their relative prices fall or incomes rise. Still, some developing countries cannot afford to import oil-based domestic fuels. In those that refine their own, an imbalance between the demand pattern and the refinery output pattern leads to a shortfall in kerosene. And the distribution channels for kerosene become increasingly weak and unreliable as one travels away from the ports and centres of production. Thus national or local market segments remain for charcoal, and they expand or contract as the supply of oil-based fuels varies. Kerosene has a refinery cut which is similar to diesel oil, and a country that wishes to minimize oil imports except for essential and irreplaceable requirements may well consider import substitution of kerosene with charcoal. Thus charcoal making survives in many developing countries as an industry, and can grow under global or national pressures to reduce oil imports.

475o (p. 119, #4)

A high proportion of energy in wood is lost in making charcoal. However, much of this lost energy would be lost in any combustion process to vaporize and drive out the moisture as well as to char and separate the noncombustible mineral elements. If these inevitable losses are excluded, the energy loss in charcoal making is not large. This is an instance where it would be wrong to think in terms of the quantity of energy without considering its quality and economics. Its smokelessness makes charcoal a preferable fuel to wood. If we are right in believing that there are no universally efficient stoves and stove efficiency is fuel-specific, charcoal could well form the fuel for a genre of efficient stoves. And its higher energy density makes charcoal cheaper to transport than wood, and therefore makes it a cheaper fuel in locations remote from wood.

476o (p. 119, #5)

We thus consider charcoal a viable urban cooking and heating fuel and capable of being developed in this role. If, however, it is to be so developed, it must be on the basis of technologies and management systems that lead to a low-priced, reliable and sustainable supply. The present predatory and energy-inefficient methods, whereby existing forests are cut down and burnt in pit kilns, are unsustainable, and it is not certain that they are cheap either.

477m (p. 98, #6) WS JG

If charcoal is to be supplied to cities on a sustainable basis, it must come from plantations that are regularly cut and replanted. Whilst energy plantations have generally been promoted on land that is unfit for agriculture, the availability of such land varies considerably from region to region. It is fairly clear that energy forestry is not competitive with agriculture anywhere, whether in developing or in industrial countries. It is not because food is more "essential" than fuel; whether it is or not depends on how much food is produced in relation to need. It is because fuel fetches too low a price relative to other agricultural products. Agriculture produces a great many products for urban markets besides food, and meets a large proportion of the fuel requirements of rural populations. It could equally meet urban fuel demand if agricultural productivity were high enough to leave a surplus of land and labour above subsistence, and if the relative price of woodfuel was high enough to make its production remunerative. Where further import-based urbanization and industrialization are no longer possible, growing quantities of both food and fuel would have to be supplied by rural to urban areas if the growth of the latter is to continue.

478o (p. 120, #7)

A charcoal industry for towns would require sustainable plantations in the first place; these are discussed in the next section. Second, it would require technological choices to be made. Charcoal-making technologies have been extensively researched and discussed (FAO 1983; Karch and Boutette 1983; Caceres 1985). There will undoubtedly be site-specific factors in actual technological choices. But in the present context a certain direction is indicated.

479m (p. 120, #8) WS

If charcoal making is to be a sustained, sedentary industry, kilns also can be sedentary; there is no special advantage in pit kilns or portable kilns. Pit kilns are the common type in Africa where a certain choice is faced between improving them and building or manufacturing more efficient kilns. Insofar as pit kilns will continue to be used, it is obviously desirable to improve them. But whether charcoal makers actually adopt improvements will depend on the economic return and the costs of improvement. Insofar as the return is largely in the form of more highly carbonized, better charcoal, more thorough carbonization would actually reduce the weight of the charcoal and would be unwelcome to the charcoal maker unless the market is sensitive to quality. On the other hand, there is a significant cost in the form of greater skill and labour in the construction of the kiln. Thus the prospects of diffusion for improvements in pit kilns are unclear. Since their technology is user-sensitive, and since it must be diffused to large numbers of users, their average practice will be much below best practice.

480m (p. 120, #9) JG

The choice would, then, fall between the brick kiln and the retort. The retort would be the right choice if there was a local demand for tars, resins and other wood chemicals; if not, the brick kiln. In Brazil, beehive kilns are used to

make charcoal for ironmaking. Beehive kilns are a fuel-efficient design with a history of at least 150 years behind them. They are also used in brickmaking and soft coke making. Their technology deserves to be widely diffused, and possible improvements in it deserve a closer look.

3. Biomass

481o (p. 122, #1)

Biomass as the term is used by energy analysts encompasses only phytomass; it does not include human beings, animals or insects. Its quality as fuel is important to the user, and depends on four major factors:

482m (p. 122, #2)

(i) **Moisture:** Water in biomass is evaporated and escapes when biomass is burnt; this process makes the heat of evaporation unavailable. The energy thus absorbed is 2.4 kJ/g of water. As a result, as moisture content increases from 0 to 50 per cent, the available energy of wood falls from 18.7 to 8.2 kJ/g (Openshaw 1984).

483o (p. 123, #3)

(ii) **Volatiles:** Wood contains tarry and resinous substances; their proportion varies between species. Their energy content is higher than that of dry wood, but they are smoky and corrosive. Incompletely burnt volatile fractions can accumulate in user equipment, such as gasifiers and engines, with serious effects.

484o (p. 123, #4)

(iii) **Noncombustible materials:** These, known as ash, do not burn, but absorb heat in combustion (to lose it later). They will thus reduce the energy density of biomass. Though not high in wood, it can be significant in straw and dung.

485o (p. 123, #5)

(iv) **Surface-to-volume ratio:** Though it does not affect the energy density of biomass, a higher ratio is related to a greater speed of burning. In cooking, which is in essence a heat exchange, a higher rate of heat production can lead to greater heat losses, lower heat transfer efficiency and higher fuel requirements. In general, the larger and thicker a piece of wood (or charcoal), the more slowly it will burn. Crop residues are generally thinner and have high surface-to-volume ratios; so also has dung.

486o (p. 123, #6)

As we discussed in section III.6 above, rural and urban demands are for different fuels. The rural population uses fuels that are abundant and near at hand, and tends to minimize labour inputs into fuel collection and production. The urban population, with its higher relative income, has stronger quality preferences, prefers better fuels. The incidence of transport costs is also high in urban fuels, so fuels with lower transport costs per unit of energy are preferred. Charcoal is therefore the leading one among locally produced urban fuels, roundwood the next one in terms of preferences. Both rural and urban areas, however, face prospective fuel shortages and rising fuel prices in countries where stocks of trees are running out. This is termed the rural energy crisis, which has attracted considerable research as well as policy action prodded by the Food and Agriculture Organization (1983).

487m (p. 196, #18) CS

The countrywise estimates of biomass supply made by David Hughart, presented in Table 12, indicate a regional dimension. It appears that the area that is most short of biofuels is the arid landmass stretching over West Asia and North Africa; higher but still low biomass availability extends at its extremities, eastwards into south, east and Southeast Asia, and southwards into Africa. This is the Afro-Asian landmass in which localities of fuel shortage must be identified, and integrated studies of fuels, cooking devices and energy-efficiency cooking practices should extend across cities and their hinterland.

TABLE 12

Estimated organic resources, 1990 (gigajoules per capita per year)

	Sustainable forest yield	Dung[1]	Crop residues	Total
Algeria	3	3 SC	1	7
Egypt	0	1 CH	6	7
Iraq	1	5 CS	2	8
Bangladesh	2	4 CS	4	10
Ethiopia	3	6 SH	3	12
Kenya	1	7 CS	4	12
Ghana	8	2 CS	2	12
Nigeria	8	3 CS	2	13
Pakistan	1	6 CS	7	14
Morocco	6	5 CS	5	16
India	6	5 CS	6	17
Sri Lanka	11	2 CS	4	17
Republic of Korea	9	1 CP	7	17
Vietnam	12	1 CP	6	19
Afghanistan	6	8 CS	7	21
Philippines	12	3 CP	7	22
China	11	3 CP	8	22
South Africa	2	8 CS	13	23
Nepal	15	11 CS	6	32
Thailand	22	3 CP	9	34
Iran	22	6 SC	7	35
Dem. People's Republic of Korea	24	1 CP	13	38
Mexico	39	9 CH	9	57
Tanzania	54	11 CS	3	68
Indonesia	63	1 CS	6	70
Chile	71	7 CS	4	82
Burma	82	4 CP	6	92
Malaysia	114	2 CP	7	123
Sudan	148	18 CS	5	171
Argentina	104	45 CS	33	182
Colombia	180	16 CH	4	200
Venezuela	211	11 CH	4	226
Brazil	229	15 CP	9	253
Peru	245	7 CS	2	254

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[1] Primary sources indicated by letter codes:
C = cattle, buffalo, camel
S = sheep, goats
H = horses, mules, asses
P = pigs

Source: Hughart (1979).

488o (p. 124, #7)

Micro evidence gives a more mixed picture (Desai 1985; Howes 1985). Rural population uses fuels that are abundant and near at hand, whether wood, crop residues or dung; within the available choice it uses higher-quality fuels; low-quality fuels like crop residues and dung are often wasted. There are considerable inequalities in access to fuel and consequently in the labour costs of fuel; the landless and the women bear the brunt of the inequalities. It is not clear whether there is an energy crisis or a crisis in income distribution, but insofar as they go together, the first is a product of the second.

489o (p. 124, #8)

Nevertheless, insofar as fuel shortage is present or incipient, the search for solutions must cover all biomass. Even where it arose from the disappearance of trees, replacing them by trees narrows down the choices unnecessarily. A large number of annual crops gives woody fuels, for instance pulses, cotton, jute and cassava. Commercial tree crops yield combustible residues. There are woody shrubs and weeds that are being used (Vasudevan and Gujral 1984; Howes 1985) or grown (Pathak et al. 1980) as fuels. A shift in the crop pattern may be an option that fits better into local climate and land use. The point applies to communally grown or exploited plantations also; broader options should be considered than trees.

490m (p. 124, #9) CS

Nontree crops need to be considered to meet urban demand, but here the specifications are narrower since low transport costs and hence high energy density are required. As has been pointed out by French (1984), forest plantations are not competitive with wood obtained by cutting down natural forests. Here too, at least a search for nontree crops which might give higher and earlier output of wood is at least worth making. Another option worth exploring is getting wood for charcoal as a byproduct, in the form of branches and tops, from plantations directed to higher-value uses like timber and paper-making. A third option is to ensure that those who cut wood either replant the trees or pay for replantation.

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VIII. ELECTRICITY

491m (p. 125, #1) MM

Electricity can be produced from a large number of primary energy sources, and is equally versatile in its uses. It has become the major source of stationary shaft power in industry both because of its convenience, efficiency and low cost relative to other prime movers using oil or coal. It is also responsible for great improvements in the quality of life, both as an illuminant and as the energy source for domestic appliances. Consequently its share of energy consumption in developing countries has shown a steady rise (Brooks 1984).

492m (p. 125, #2) MM

Electricity is produced in all developing countries, and improvements in its production and management are of general interest to all. It offers some of the most promising avenues of research.

Power sector organization, management and policy

493m (p. 125, #3) MM

Since electricity systems are either state-owned or regulated, they offer great scope for microeconomic policy. Power systems are also capital-intensive, and have relatively low running costs; if simple short-run marginal cost pricing was applied to them, major losses would result. The opportunity and the challenge have attracted some of the best talents to power system economics (Turvey and Anderson 1977; Munasinghe and Warford 1982; Munasinghe 1983). However, the gap between promise and performance is often wide in the power sector.

494n MM

The electricity sector in most developing countries has developed rapidly especially since the 1950s. Since it is the most capital-intensive sector of the economy, potentially capable of generating significant revenues, and also dependent on relatively modern technology, electricity has tended to attract greater foreign involvement throughout the Third World. Typically, power supply was originally available only in the main cities, and produced by isolated thermal or hydro plants of relatively modest size. These plants were often associated with large industrial users and foreign companies.

495n MM

As more developing countries received independence during the post-second world war period, and consumer demand began to grow, it became advantageous to develop interconnected grids -- at the regional and national levels -- as well as larger generating stations, to realise economies of scale in planning and operations, greater reliability, improvements in coordination and efficiency and other benefits. At the same time, socioeconomic pressures compelled many governments to take over private power producers (both local and foreign), and also centralize the supply of electricity.

496n MM

The principal objective of electricity supply is to meet the load. A modern power company is expected to perform the following technical functions efficiently in order to provide satisfactory services to its customers: (a) demand forecasting (short, medium and long run); (b) long-run, least-cost investment planning to meet the future demand at an acceptable quality of supply (generation, transmission and distribution systems); (c) optimal operation and maintenance of the power system (including system security, losses, etc.), and (d) price setting.

497n MM

Based on a study of some of the more successful developing country power utilities, it is possible to identify several desirable characteristics that will help to ensure that an electricity supplier would be able to perform satisfactorily. Few developing-country institutions have been able to meet all the criteria at any given time. However, while the process is never complete, there should always be progress towards one or more of the goals that have not yet been reached.

498n MM

A successful power utility should have:

(a) Clearcut general, national-level policy guidelines provided by the government, but without involvement in daily activities;

(b) A relatively independent Board of Directors that will interpret the national guidelines, provide more specific policy directives and generally protect the management from undue interference;

(c) A competent and well-motivated management, with a high degree of continuity;

(d) The authority to recruit good staff, and retain them by offering competitive salaries and other incentives, as well as to dismiss incompetent staff;

(e) A high degree of financial viability and independence, including the ability to set tariffs that will raise sufficient revenues, help meet social-subsidy objectives, ensure economic efficiency, and so on;

(f) Primary responsibility for the procurement of goods and services; and

(g) A separate, unbiased and fair regulatory environment that focusses on policy concerns (e.g., investment and pricing issues) rather than minor aspects that can lead to undue interference and delays in decisionmaking.

499n MM

In actual practice, few if any of these requirements are satisfied in all but a handful of developing countries. Typically, political pressure to keep tariffs low will lead to inadequate financing, underinvestment, and poor upkeep of the power systems. Quality of supply could deteriorate while outages and losses mount, imposing further burdens on the utility as well as on the consumers. Interference with management decisions on staff, procurement and even daily operational matters, as well as frequent replacement of senior managers, may undermine both competence and morale. Concurrently, rising consumer demand and expectations, fuelled by political rhetoric (especially regarding rural electrification), will further exacerbate the situation.

500m (p. 127, #7) MM

More recently, the average cost and subsidized pricing policies of large utilities may be preventing investment in small-scale power generation systems -- for instance, photovoltaic, wind-powered or small hydropowered -- which could supply power locally at a cost below the marginal costs of generation and distribution from the large systems. They have also reduced the savings that the consumer would achieve by conserving electricity, and discouraged the return on investment in electricity saving (Brooks 1984).

501n MM

The focus of structural reform in the electricity sector should be on achieving certain desirable characteristics and peformance. Although these attributes are frequently associated with private utilities, it does not mean that the solution is privatization. It is possible to achieve the desirable characteristics while remaining under government ownership, providing other reforms are carried out. In other words, the choice of organizational framework is not necessarily between the extremes of rigid centralized government control and complete privatization -- viable intermediate solutions are feasible.

502n MM

The tendency towards centralization has been based on valid reasons in practically all cases. Most Third World countries are seeking to deal with the most basic problems such as the fragmentation of the sector, inadequacy of qualified staff, poor planning, interference, etc. A sudden and unplanned push towards privatization and decentralization may introduce further unfamiliar and uncontrollable variables, thus exacerbating the situation and even diverting resources required to address more basic issues, especially among the poorer

countries. In particular, while complete deregulation and privatization approaching the ideal of perfect competition is widely accepted as unworkable, even the mix of regulation and competition that is now under serious study in the market economies is likely to be far too complicated for most developing countries.

503n MM

The problem of institutional reform is complicated by the need to maintain continuity, and not subject the often fragile fabric of a developing country's power sector to violent changes, with unforeseen consequences. Structural shifts should be more of a transition type that take the existing institutional framework and sociopolitical and economic constraints into account, and build on past experience.

504n MM

The conditions that determine whether electricity supply in a given country exhibits natural monopoly characteristics should be carefully studied in relation to the multistage aspects of the power system (i.e., generation, transmission and distribution). Economies of vertical integration and coordination, within and between stages, should also be examined. More generally, the overall philosophy underlying the macroeconomy (e.g., socialist-planned, mixed, capitalist), the existing degree of reliance on market mechanisms and the degree of access to capital markets by autonomous institutions are equally important factors to consider in making decisions concerning the institutional framework and sector policy.

505n MM

The principal area for reform is likely to be distribution. The spinning-off of the distribution function from bulk supply is usually a relatively uncomplicated step in the right direction. In large power markets, some competition at the generation level could also be encouraged on an experimental basis -- starting possibly through the process of industrial cogeneration. The legal and contractual problems are likely to be more formidable than the technical ones.

506n MM

Organizational reforms will generally not result in significant benefits in the efficient pricing of electricity, although areas of implementation such as metering, billing and revenue collection may improve. Therefore, the promotion of tariff policy reforms (i.e., through the use of long-run marginal cost-based pricing structures), should continue to be pursued irrespective of the policy on power sector reorganization.

507n MM

The experience of other countries should be monitored. Further country-specific case studies should be carried out. Developments in other related sectors like telecommunciations and natural gas are also relevant.

508m (p. 127, #9) MM

Further applied research is required to determine to what extent it is possible to adapt utility organization to the new technological conditions. In larger countries, transmission grids may permit competition between a number of generating plants, whose number would be even larger if marginal cost pricing gave a chance to new technologies. A possible longer-term reorganization of the power industry that can be envisaged is one in which separate enterprises would manage (i) individual generating plants; (ii) long-distance transmission grids and (iii) load distribution centres such as towns or districts. Transmission grids would function as common carriers between generating and distribution centres which would trade electricity by means of long-term contracts. Plants would be able to choose customers and distribution centres would be able to choose suppliers. The contracted prices can embody variations of marginal cost pricing, and can even be fixed for very short time periods using the newly available means of two-way communciation (Tabors 1984). Prices charged by the distribution companies to final consumers would have to be fixed and announced in advance, but here too two-part and time-of-day tariffs and buy-back of power at avoided costs can give full scope to decentralized generating devices and to energy saving.

509m (p. 128, #10) MM
Thus, there is much scope for further development along these lines and we think that organizational innovation in the power industry and related economic issues form one of the most promising areas of research in developing countries.

Optimizing investment planning, pricing and operations

510n MM
The two principal policy decisions to be taken by power utilities relate to investments in and the pricing of electricity; therefore, both areas are prime candidates for further research. In most developing countries where the government is the main supplier of electricity services, it can intervene directly in the sector. Successful policy analysis and formulation requires the following items. First, the national and corporate policy objectives must be clearly defined. Second, the policy models must explicitly define and quantify the most important technical-economic relationships within the electricity sector and interactions with the outside world. Third, other social and political constraints that are difficult to quantify must be systematically accounted for. Finally, the results should be readily translatable into straightforward policy options and the methodology should be practical and applicable even when data are poor.
511n MM
From the engineering-economic viewpoint, the basic objective of analysis is to determine a set of policies that will maximize the net benefits of electricity consumption to society as a whole. This also corresponds to the most efficient use of scarce economic resources and maximization of output or GDP based on the national economic viewpoint. There are several other important objectives such as meeting the basic energy needs of poor consumers, independence from foreign sources, raising financial resources for future investments, etc., which will also influence both pricing and investment policy.
512n MM
In investment policy, the principle of maximizing net benefits may be used to optimize overall planning, reliability and losses. Often the maximization-of-net-benefits criterion may be reduced to the simpler rule of minimizing total costs such as for least-cost investment planning. In recent times sophisticated system planning models and techniques have been developed, based on the criterion of minimizing the cost of supplying a given long-range demand forecast at some acceptable reliability level (or quality of supply). The optimal size, mix and timing of new capacity additions are treated in this way, and related models also provide for optimal (least cost) operation of the system.
513n MM
Currently a new approach involving the minimization of total costs which includes both supply costs and shortage costs (i.e., costs incurred by consumers due to unreliable supply) is being explored. Methods of measuring shortage costs in developing countries need to be further researched.
514n MM
In pricing policy, the basic economic principle requires that prices reflect the marginal costs of supply, thus ensuring that economic efficiency criteria are satisfied. However, these marginal costs must be systematically adjusted to yield a practical tariff structure that meets other national policy objectives such as supplying the basic electricity needs of poor consumers, ensuring financial viabilty, price stability, and so on.
515n MM
Whilst the close relationship between optimal investment and pricing policies has been recognized for some time, these links were systematically analyzed only in some of the more recent studies. By explicitly incorporating effects due to the stochasticity of supply and demand, and introducing the notion of shortage or outage costs in welfare maximizing models of electricity consumption, it has been shown that the optimal conditions for price and capacity levels must be simultaneously satisfied. In this context, determining the optimal capacity level is equivalent to

establishing the optimal level of reliability (or lower consumer outage costs) and vice versa. Problems relating to the dichotomy of having to choose between short- and long-run marginal costs, and the correct allocation of capacity costs among peak, shoulder and off-peak consumers, have been illuminated in recent work.

516n MM

We may summarize this complex analysis in simple terms, as follows: The optimal price is the marginal cost of supply. Simultaneously, the optimal reliability (capacity) level is defined as the point at which the marginal costs of increasing reliability are exactly equal to the corresponding reduction in marginal outage costs of consumers. Furthermore, let us define the short-run marginal costs (SRMC) as the cost of meeting additional electricity consumption, with capacity fixed, while the long-run marginal costs (LRMC) are the cost of providing an increase in consumption (sustained indefinitely into the future) in a situation where optimal capacity adjustments are possible. When the system is optimally planned and operated (i.e., capacity and reliability are optimal), SRMC and LRMC coincide. However, if the system plan is sub-optimal, significant deviations between SRMC and LRMC will have to be resolved within the pricing policy framework. Finally, if there are substantial outage costs outside the peak period, then the optimal marginal capacity costs may be allocated among the different rating periods (i.e., peak, intermediate and off-peak), in proportion to the corresponding marginal outage costs. For practical application, LRMC is the most convenient benchmark for price setting.

517n MM

The worldwide scarcity of energy resources and the increasing costs of energy supply have highlighted the importance of energy conservation and elimination of waste by both producers and users of energy. Power system loss reduction is one of the principal ways for achieving this in the electricity power sector.

518n MM

In the process of delivering electricity to consumers, losses are incurred at the generation, transmission and distribution stages of a power system. Generation losses may be reduced by improving the efficiency of plant and reducing station-use, e.g., using new technologies like combined-cycle thermal plant, replacing old boilers and generally uprating old thermal generations, using higher efficiency designs in new hydro installations or replacing older turbines, etc. Leaving generation aside (where acceptable norms for losses vary according to the mix of plant), recent work indicates that average energy losses in the power delivery system, i.e., transmission and distribution, should normally be below 10 per cent of gross generation, whilst economically optimal loss levels may be as low as 5 per cent. The corresponding losses in many LDC networks approach 20 per cent, even after allowing for substantial amounts of theft.

519n MM

The basic principle involved is minimization of overall supply costs, defined as the sum of system costs and value of system losses. Modest investments in system rehabilitation can often yield a more than commensurate reduction in losses. In other words, reducing losses is often far more cost-effective than building further supply facilities to feed those losses.

520m (p. 128-129, #11-15) MM

An important area for improving operations concerns plant availability which is observed to be low in many developed countries (Khatib 1983). The principal causes are:

(i) **Poor system configuration:** Lack of an integrated grid may make it impossible to stabilize the system; or the proportion of large plants in a system may be too high given the spinning reserve.

(ii) **Unbalanced investment:** Inadequate quantities of spare parts may be carried; or there may not be enough reserve capacity in the auxiliary, control and protection systems.

(iii) **Operational constraints:** The fuel may be inconsistent with the plant, or there may be a shortage of expert manpower.

(iv) **Plant derating:** Mishandling may lead to a fall in plant capacity.

521o (p. 129, #16)
Remedial diagnostics of specific plants and systems are of considerable potential utility.

Power equipment

522o (p. 129, #17) ZYJ
The power systems of developing countries are considerably smaller than those of industrial countries, and typically take smaller plants. Such small power equipment is not a major product of the large plant manufacturers but is produced on demand by them. However, there is a steady demand for them, and if they were standardized at ratings in the range of 25-250 MW, serial production would lead to economies of scale and incremental innovation. This type of production would be more feasible if it was the joint programme of a number of developing countries.

523n MM
In general, the developing countries do not have a comparative advantage in research and development on hardware relating to sophisticated generation, transmission and distribution equipment. Large countries such as Brazil, the China and India may have the resources and internal markets to support such efforts on a modest scale. Joint ventures with foreign companies are another option.

Hydroelectric power

524n MM
Hydroelectricity is still one of the world's major unused energy resources, with only about 20 per cent of the total exploitable potential presently harnessed. Although a few developing countries rely heavily on hydropower, the Third World as a whole is using less than 10 per cent of its hydel potential -- the corresponding figure for the industrial countries, over 30 per cent, is much higher.

525n MM
From the research viewpoint, the technology is relatively well developed and mature. Much of the knowhow for building large installations remains with firms in the industrialized countries, although a few companies and utilities, especially in some of the larger developed countries, have also acquired considerable experience in recent years.

526n MM
The main scope for research and development by the developing countries in this area concerns small-scale hydropower (SSHP). SSHP comprises three ranges which are approximately 0-50 kW - micro, 51-2000 kW - mini and 2-5 MW - small, respectively. The definition of ranges is not very rigid and there is also considerable overlap.

527n MM
Small hydro sites are essentially scaled down versions of large hydro installations, and usually consist of dams, powerhouses and penstocks tied to a distribution grid. Minihydro systems are basically pumps operated in reverse, using small diversion weirs and canals rather than dams. The generators are housed in small structures which are like pumphouses, while the water is brought into the turbines through conventional-type pipes. Microhydro installations are of the same type but much smaller. The turbines used are frequently centrifugal pumps operated in reverse.

528n MM ZYJ
R&D efforts could be profitably focussed on means of simplifying designs and use of local materials, etc., to promote more cost-effective fabrication and installation of these plants in the developing countries. In doing so, the considerable experience of China in the fabrication and installation of small-scale hydro power plants could provide a useful starting point.

1. Nuclear Power

529m (p. 130, #1) JG

As the Energy Research Group, we do not wish to concern ourselves with the nonenergy or nonresearch aspects of nuclear power. Experimental nuclear reactors are easy to set up, not too costly, and enormous fun for nuclear scientists. It is not too difficult even to make nuclear bombs. But neither small reactors nor bombs have much significance as far as energy is concerned. If a country intends to go in for nuclear power, it would find it useful to have scientists who have played around with small reactors; but it would find even more useful scientists who have worked in nuclear power plants. Further, the technology of large nuclear power reactors (though not of their downstream steam turbines) is so demanding that no developing country is likely to undertake nuclear power generation in the next few decades without the helping hand of a country that currently produces nuclear power. Nuclear power has required and generated considerable research in Argentina and India, the two countries which have tried to develop their own capacity, but it is unlikely that other countries will follow the lead of those two countries in building up indigenous technological capacity; most others are likely to get plants and technology on licence from existing suppliers in industrial countries.

530o (p. 130, #2)

Even with the collaboration of a nuclear plant supplier, the initial investment in training and infrastructure is substantial (Chung 1985; Woite 1985). Hence a country would find it more economical if it took an advance decision to build a series of nuclear power plants; a one-off plant is inadvisable. This condition, together with the large minimum size of plant, makes nuclear power an option worth considering in 10-15 developing countries (Desai 1984; Obermair 1984). The prospects would change if nuclear plant producers developed smaller reactors for the developing country market. There are pronounced economies of scale in nuclear power plants; they have led to the standardization of plants around 1000 MW in all industrial countries. The current slump in the market in industrial countries makes small plants attractive to nuclear plant manufacturers, and a number of alternatives are being explored (Egan 1984). But the plans are at present in a conceptual stage. To work them up into operational designs would require expensive and time-consuming development work. The funds for it are unavailable with the manufacturers or from their governments; nor are there developing countries at hand which cannot afford 1000 MW plants but can finance a development programme for 300-600 MW plants.

531m (p. 131, #3) WS

Nuclear energy is of interest to developing countries which are faced with payments problems arising out of energy imports, or which are exporters of exhaustible resources that are expected to run out -- although, if a country finances imported nuclear plants out of borrowings and fails to run them efficiently, it may actually worsen its balance of payments. Nuclear plants are also of interest to countries like China and India, which have transport capacity strained by fuel traffic. Thus we do not doubt the relevance of nuclear power to developing countries. But we cannot see any directions in which they as a group need to build up autonomous research capability.

2. Solar Photovoltaic Systems

532o (p. 132, #1)

The solar energy potential of developing countries, most of which are tropical or subtropical, has long been recognized. It is of particular interest to the arid countries of West Asia and North Africa, which receive intense solar radiation for a

large part of the year (Kettani 1982). Despite the fact that interest in solar energy goes back almost 30 years (United Nations Educational, Scientific and Cultural Organization 1956), the practical consequences are yet modest. The prospects are different for solar photovoltaic systems on the one hand and solar thermal applications on the other; the latter are therefore discussed separately in the next section and the next chapter.

533o (p. 132, #2)

Absence of pronounced economies of scale makes pv systems attractive for stand-alone uses in locations away from grids. But the capital costs per watt are still high, so the technology is better suited to low-voltage uses. Radio, television and telecommunications are the obvious ones, but lighting is also attractive. All these uses require storage; however, the costs of battery storage are avoided if the power is fed into the grid. In countries with high diurnal peak demand (e.g., where cooling and refrigeration are important and where residential and commercial demand dominates the load curve), grid-connected systems would make sense.

534o (p. 132, #3)

Both stand-alone and grid-connected systems require power conditioning equipment, whose cost will be relatively more important in smaller systems. In stand-alone systems, the equipment varies with the type of application; for instance, AC loads would require a voltage controller and a self-commutated invertor. Grid-connected systems require simpler and cheaper invertors along with harmonic filters to suppress the injection of electrical noise into the grid.

Current pv sytems

535m (p. 133, #4-8)

The current pv systems, based on monocrystalline and polycrystalline silicon, involve four stages of manufacture (Luque 1984; Mintzer 1984; Backus 1984a, 1984b):

(i) **Production of silicon:** Here efforts to reduce costs have involved a reduction in the purity of silicon. However, a reduction in purity has a trade-off in the form of a deterioration in cell efficiency, so the opportunities of cost reduction are limited.

(ii) **Sheet manufacture:** Recent developments, namely single-crystal continuous sheets and polycrystalline silicon wafers, also reduce cost as well as efficiency.

(iii) **Cell manufacture:** Here the technology is not changing much; it has perhaps been frozen as a result of the automation of operations.

(iv) **Panel manufacture:** Here efforts are being made to increase cell output by using concentrators. This would limit pv cells to the use of direct sunlight, and require trackers. Trackers introduce economies of scale in operation, and raise the minimum economic size of generation plant to 3 MW.

536o (p. 133, #9)

There has been a rapid fall in the cost of pv modules; from $50/peak Watt in 1973 it came down to $6 in 1984. But recent years have also witnessed a price war between the subsidiaries of oil companies and other manufacturers. When the war ends, cell prices may well rise. In any case, major cost-reducing innovations look unlikely in conventional pv cell manufacture.

Developments in prospect

537o (p. 134, #10)
Thin film cells are uncompetitive at present, but offer greater hope of innovations; they are also much easier to make. Their efficiency is low at present; so also is their stability outdoors. Of the two kinds of thin film cells, compound semiconductor cells and amorphous silicon cells, the latter hold great interest.

538m
Compared to crystalline cells, amorphous silicon cells have better optical absorption and better photoconducting properties for the solar spectrum. They also use less silicon. At present they are mainly used in watches and calculators. But they can be deposited on any noncrystalline substance. Thus in Japan they have been deposited on polymer films, stainless steel substrates and ceramic substrates; Sanyo is in the process of depositing them on roofing tiles. Their efficiency is reported to be about 10 per cent in commercial applications (Hamakawa 1985).

539m CS
The ease of making thin film cells has led to the proliferation of research on them in developing countries. When the technology reaches the commercialization stage it will require different skills; but until then it suffers from no handicaps. Thus research on thin film cell technology appears particularly promising for developing countries; it would be helped even more by the creation of communication networks among researchers in developing countries.

3. Solar Thermal Electricity

540o (p. 135, #1)
Solar radiation is very diffuse; as Tabor (1981) pointed out,

> "...if we take the world average solar radiation at about 200 W/m^2 (continuous) or 17 MJ/m^2 per day, we would require some 260 m^2 of collector to replace one barrel of oil a day, if a collector were 100 percent efficient: in practice, the efficiencies are very much lower so that considerably larger areas are needed."

541o (p. 135, #2)
In fact, the Solar One 10 MW central receiver power plant used 1818 heliostats of 39 m^2 each, achieved 13 per cent average efficiency, produced 71 MWh/day in a location where insolation was 950-990 W/m^2 and when an average day had 10-11 hours of sunshine, and cost $13/We (Weingart 1984). In places with lower insolation or fewer sunshine hours, the capital costs would be still higher. Undoubtedly the technology will improve and costs decline as new prototypes are built. But just now this is a submarginal technology, and its future is speculative. So we do not see any justification for research on it in developing countries at present.

4. Wind Generation

542o (p. 136, #1)
Wind generators may be stand-alone or grid-connected. Stand-alone generators have a potential market in developing countries in areas which the grid cannot reach. They require batteries. Battery sizing to achieve reliability at a low cost would be important, and would require site-specific calculations.

543o (p. 136, #2)

Grid-connected generators do not need batteries; they can also exploit economies of scale, since their output is not limited by local demand. Hence their capital costs are lower (Piepers 1985).

544o (p. 136, #3)

Most of the development in wind generators has been towards grid-connected machines in the USA. Besides the good wind regime in parts of the USA, there are three reasons for this -- (a) tax incentives or direct government purchase assistance to encourage the purchasers of grid-connected machines, (b) government instructions to utilities to purchase electricity at avoidable cost, and (c) a wind generator with grid connection is a more marketable and profitable proposition for manufacturers in the USA because a majority of potential consumers of electricity are already grid-connected (Merriam 1984).

545o (p. 136, #4)

A majority of the grid-connected machines are horizontal axis machines and their technology is fairly well proven. Though vertical axis machines like Savonius and Darrieus machines have been developed, they have yet to reach a point where they prove to be as reliable and efficient as horizontal axis devices (Kristoferson et al. 1984). A major problem with vertical axis machines is that they cannot be furled and need other methods of speed control.

546o (p. 136, #5)

This relates to the major operational problem in grid-connected wind generators, i.e., that of power control so that the stability of the connected power systems can be maintained. Power limit operation from horizontal axis wind generators is achieved through pitch control whereas in vertical axis wind generators some form of spoilers or aerodynamic braking is used (Quraeshi et al. 1984). The need for voltage and reactive power control has direct consequences for the choice of the generator. The trend in commercial machines at present seems to be -- (a) fixed pitch with overspeed control and an induction generator and (b) variable pitch with a synchronous generator (Sexon et al. 1981).

547o (p. 137, #6)

Whilst there have been attempts at using wind generators in parallel with diesel generators in some industrial countries, problems can occur when the diesel generator is called on to change its output frequently as wind energy availability fluctuates. Besides decreasing the oil saving potential of the diesel generator, this may lead to more frequent overhauls of the generator. A consequence in both cases would be increased costs (Kristoferson et al. 1984). A way around this problem would be to interpolate battery storage. This would be easier on the diesel engine, but would add to costs.

548e JG

A wind generation programme will require detailed site-specific research to determine whether the wind regime is appropriate for generation: the windspeeds should neither be too low for generation nor so high as to require unduly strong and expensive structures. Thus the number of sites for wind generators is likely to be limited; it will determine the maximum extent of the market from them, within which they could be installed where they are found economical. If a developing country gets this far, it will need to standardize a design for production. It would be well advised to choose the largest size that can be economically produced, in view of the fact that the power output of a windmill varies in proportion to the square of its wingspan. The major problems of technical research it will encounter are likely to be on the generation-transmission interface.

IX. THERMAL ENERGY

549o (p. 138, #1)

A nonenergy product, when hot, can act as a carrier and a source of energy; many energy-using processes generate heat as a byproduct which can be used further. The opportunities of recovering byproduct heat are numerous in industry. Since heat is readily transferred from hotter to colder objects, it is rapidly dissipated if anything hotter than ambient atmosphere is exposed to the air. The only way of preventing its dissipation is to enclose it in media that are poor conductors of energy: thus insulation is the other important means of heat conservation in industry. Both heat recovery and insulation were discussed in section III. 2 above. Since, however, heat is easily dissipated, and its value is seldom high enough to justify storage or transport, it is usually used where and when it is available. Here we discuss two forms of heat: geothermal and solar thermal energy.

1. Geothermal Energy

550m (p. 139, #1) AK

The heat stored in the upper 3 km of the earth's crust under land areas is estimated to be 10^{14} times as much as the total energy in fossil fuel and nuclear resources. The obstacles to its exploitation relate to its cost and quality (Fridleifsson 1984).

551o (p. 139, #2)

To bring the subterranean heat to the earth's surface, a medium is necessary; the only practical medium proved to date is water. A great deal of water is stored underground; for it to retain heat, however, it is necessary that it should not be in contact with water on the surface. Thus hot springs are seldom an indication of the availability of high-temperature steam. It is necessary that the water should be trapped underground. At the same time, if it is to be brought to the ground, a permeable path for it is essential. These are the special conditions in which subterranean water must be found to be exploitable. In addition, the cost of exploiting it will depend on its depth, temperature, pressure, and the difficulty of drilling for it.

552o (p. 139, #3)

The first step in the exploitation of geothermal energy is the establishment, delineation and estimation of the resources; this requries on-site exploration. Many geopressured fields have been discovered in the course of oil exploration. But the occurrence of steam or hot water fields does not coincide with that of hydrocarbons. Hydrocarbons are found in or near sedimentary systems; geothermal systems which hold water over 200°C are more likely to be found in young igneous systems. Such high-temperature steam can be used directly to generate electricity. High-temperature steam used in a multi-flash unit would be particularly economic. However, steam pressure declines as a geothermal field ages, and the number of flashes for which it can be used will also decrease.

553o (p. 140, #4)

The occurrence of geothermal resources is much greater for water at lower temperatures whose use for electricity generation is not economic. Such hot water can be used for district heating; indeed, it is being so used in Beijing and Paris. It can also be used in greenhouses and for fish culture in cold areas. Where there are concentrations of industries using large quantities of steam, the use of hot geothermal water would save energy. But the chemical content of geothermal water can pose problems of corrosion and environmental pollution.

554o (p. 140, #5)

Exploration for geothermal resources is worthwhile in countries with favourable geology. For countries with large, low-grade geothermal resources, keeping up with and perhaps participating in research on binary cycle plants would be well advised. Hot dry rock technology is in too early a stage of research for firm indications of its prospects to emerge. But the European Commission's and the US experiments are certainly worth keeping a watch on.

2. Solar Thermal Energy

555o (p. 141, #1)

As we pointed out in section VII. 3, solar radiation is very diffuse. The higher the temperature, the more it has to be concentrated. Thus high-temperature applications require large reflectors spread over extensive areas coordinated with tracking mechanisms. Capital costs are much lower in devices that do not require concentration or tracking, and which therefore operate at low temperatures. These are essentially devices that achieve moderately higher-than-ambient temperatures by trapping solar energy: for instance, water heaters, dryers, cookers and stills. Because they do not concentrate radiation, economies of scale are exhausted at a relatively modest size; they are therefore largely for use in households and small industry. However, this does not mean that there are necessarily no economies of scale in their manufacture. Possibilities of economies of scale depend on design and engineering. Hitherto most of the research on these devices has been done by researchers interested in making and testing prototypes. Most have not given thought to the problems of production; those who have, have tended to assume that production would be on order or in small batches. If, however, any of these devices are to be adopted in developing countries on a large scale, as much thought would have to go into their production technology as into product design.

556o (p. 141, #2)

Variations in sunshine hours and intensity of radiation imply that these devices would either have to be oversized and underutilized, or used in conjunction with devices using conventional fuels, or both. Their economics is thus determined by savings in alternative fuels, and not by savings in capital expenditure on other devices.

557o (p. 142, #3)

They are all medium-temperature devices operating at temperatures between 60°C and 150°C. Amongst them, devices operating at high temperatures are less economic because they require more expensive materials and work under more severe operating conditions. Hence the economically viable devices are likely to be ones operating at relatively low temperatures (Collins 1985). Where they are used in conjunction with conventional devices, therefore, the latter are likely to act as boosters.

Water heaters

558m JG

Solar water heaters are common in Japan, Israel and Australia. They are manufactured by firms which are small by the standards of those countries and by no means large by developing country standards. However, the firms are basically assemblers that buy in components. In all three countries there are seasons when insolation is high but ambient temperatures are low enough for hot water to be preferred. Applications in developing countries will be appropriate where climatic conditions are similar -- in temperate or subtropical regions as well as dry, hilly areas. However, their economics will depend critically on the relative price of electricity or oil where these are available. Water heaters are a mature product,

and its research requirements are modest. But if installed in large, multi-unit residences they can pose problems of interfacing with plumbing systems (Isaza 1984).

Cookers

559o (p. 143, #5)

Concentrating cookers are unlikely to find large markets in developing countries. They are expensive and hence appropriate at relatively high incomes, and they are more inconvenient to operate than high-income families would tolerate.

560o (p. 143, #6)

Flat-plate cookers are limited in the variety of cooking operations to boiling, steaming and baking. They are slow, and do not necessarily cook at a time when food is required. Their effectiveness varies from season to season. On the other hand, they are relatively cheap, and could get cheaper if they were properly engineered and commercially produced. They also require no attention when cooking. They can best be used as an ancillary device, and must economically justify themselves in terms of the fuel saved on the main device. They thus probably have greater appeal for households which have another main device that uses an expensive fuel -- which may be kerosene, LPG or charcoal. It is unpromising to promote solar cookers as a poor man's device -- at least in low-income countries -- and market identification and development for scale production are necessary for their success.

Stills

561o (p. 143, #7)

As long as the solar still is designed as a simple heat trap, there are no economies of size; and the communities that demand desalinated water have large requirements. Hence despite decades of experiments with solar stills, most of the desalination is done in large-scale fossil-fuelled plants in countries that are rich in oil. Solar stills are unlikely to become large-scale suppliers of fresh water. But small models should be supported as a health-promoting device for drinking water in areas which have polluted water or endemic water-borne diseases.

Pumps

562o (p. 144, #8)

The capital costs of solar thermodynamic pumps should come down considerably if they are to compete with photovoltaic systems even at current costs. The development work necessary to make pumps competitive is likely to be expensive. Given the present and prospective funding levels, research in this area is likely to have modest success (McNelis and Fraenkel 1984).

Crop dryers

563e

Drying is a thermal process; apart from all fuels and electricity it can use solar heat as well. There have been extensive experiments with solar dryers in developing countries. The constraints on their application are twofold. First, it is possible to dry many products by just spreading them out in sunshine, without incurring the capital expenditure on dryers. Where such ambient drying is feasible,

the onlv justification for dryers would be in the effect they have on the quality of the product; for instance, they may keep out dust, prevent birds or insects from attacking the product, or prevent contamination by foreign organisms. There are few applications where these marginal improvements can make a decisive difference: for instance, dirt added in the open can be washed, birds and insects can be kept out in other ways, and except in some medical uses, contamination is not a serious drawback (solar dryers have been devised for sterilization of medical equipment, but they require to reach higher temperatures, and are therefore more costly).

5640 (p. 145, #10)

Second, the temperatures that can be reached in simple solar dryers limit their throughput, and make them inappropriate where the volume of throughput has to be large or where the drying has to be done rapidly. Ordinarily, the investment required in a solar dryer can be afforded only by a producer with relatively substantial means, and his output may well be so large that a diesel or electric dryer is cheaper for him than a battery of solar dryers. Also, artificial drying is generally resorted to when ambient drying is impossible: for instance, when multiple cropping requires a crop to be harvested before it is dry on the ground, or when the weather in the post-harvest season is too rainy or cold to allow outdoor drving.

5650 (p. 145, #11)

It seems to us that where solar drvers have a market, they will invariably have competition from fuel-using or electric drvers. Apart from being slow, the present solar dryers also require manual handling of products, whilst diesel or electric drvers can easily incorporate a motor to move the grain in and out. Hence the economics of solar dryers is precarious (Bruggink 1984). But there seems to be greater scope for hybrid dryers, in which air used in diesel or electric dryers is preheated with solar heat.

X. MOTIVE POWER SOURCES

566o (p. 146, #1)

Whilst a great deal of energy in industry, agriculture and transport is used for work, motion, draught power and shaft power, only three sources directly supply energy in those forms: wind, flowing water and animate sources. Wind power has always been of small importance, and is unlikely to become a major source of energy. Water power was important as a source of industrial energy in a few locations before the advent of prime movers; now it is used only to produce electricty.

567o (p. 146, #2)

Animate power was the major source of motive power before the industrial revolution. Since then inanimate sources have both replaced it and supplemented it in industrial countries. The quantities used in industrial countries now are small compared to those from inanimate sources; and most human workers are engaged in nonphysical work.

568m (p. 146, #3) JG

In developing countries also supply from inanimate sources has been growing, and it outweighs supply from animate sources in many. But the proportion of animate to inanimate energy varies considerably from sector to sector, and animate energy remains important in agriculture and small-scale transport. Certainly, a high proportion of the working population earns its living by physical labour. Since development consists as much of a change in the quality of work as a rise in the standard of living, human energy and its use are one of the most important areas of knowledge. But as we shall see, the state of research on it is chaotic.

1. Wind Energy

569o (p. 147, #1)

The time pattern of wind energy supply is highly variable and erratic, and a windmill magnifies the effect of windspeed (Jarass et al. 1981). Hence it can be used for operations which are not time-dependent, or in conjunction with energy storage, or in conjunction with a complementary source of energy output. It needs to have a higher starting torque and hence higher windspeed if it is to do work than if it is to generate power. Hence the design of wind generators is very different from that of other windmills. Wind generators are light, and have a small number of blades whose pitch is so designed as to pick up light winds. Other windmills are more often multibladed and are designed to extract more work.

570o (p. 147, #2)

Whilst stronger winds mean more power to be harvested, they also require stronger windmill structures; hence capital costs go up with the maximum windspeed, and if windspeeds are too high, windmills might become too costly to be economical. Even if they are viable, it is necessary to prevent them from being damaged by high winds. This is done by changing the orientation of the rotor to the wind or the pitch of the blades. If done manually, it involves constant human supervision and consequent labour costs; if done by servomechanisms, it raises capital costs. Exposure to elements and stress on moving parts also implies frequent maintenance. Thus the capital costs of windmills can be high, and the running costs are by no means negligible.

571o (p. 148, #4)

Windmills cannot be used directly, but are invariably used with an energy converter such as a generator or a pump. In order to minimize costs, it is necessary to match the *wind regime, the windmill* and the converter. This is a site-specific task of some mathematical complexity. At the same time, the windmills and the converters need to be produced on a certain minimum scale to bring down costs. Hence integrated planning of windmill systems can pay considerable dividends.

572o (p. 148, #5)

We have discussed wind generators in section VIII.3; here we shall confine ourselves to irrigation pumps. Within these, there are two distinct end-use categories -- water supply windpumps and irrigation windpumps. Water supply windpumps need to be reliable, to run unattended for most of the time and to require the minimum of maintenance. Thus they tend to be quite expensive in relation to their power output. They are industrially manufactured using steel components and have automatic protection devices to prevent overspeeding in storms (McNelis and Fraenkel 1984). Traditional multiblade farm windpumps and their modern-day counterparts fall into this category of end use. Traditional multiblade windpumps tend to be heavy, material-intensive and complicated to assemble but they are robust and reliable. Their modern counterparts tend to be lighter because they use construction tubes instead of rolled sections. Their modular subassemblies result in structural simplicity and are easier to manufacture. They can also be used for higher wind-speed regimes with electric drives (IT Power 1983).

573o (p. 148, #6)

Irrigation windpumps are used only seasonally, and it is less important to have a machine that can be left unattended than one which is low cost. So irrigation windpumps tend to be of indigenous or local designs that are often improvized or built by farmers using local materials to achieve low-cost mechanization. Most of these "self-built" machines are made of wood or basic steel structural components and use cloth or wooden sails. Their efficiency is typically half of that of water supply windpumps, and they may need relatively frequent oiling and adjustment.

574o (p. 149, #7)

Whilst the old designs tend to be more reliable, they are heavy, expensive to ship and complicated to assemble. But on the other hand, the newer designs do not have a proven field performance record either in terms of their efficiency or their life span. Attempts at transferring the technology of low-cost irrigation windpumps from one region to another have tended to fail. A possible reason could be a mismatch between wind regimes, irrigation requirements and pump capacity. But yet another important reason could be not viewing the low cost of a windpump as a direct function of the cost of raw materials and labour. Thus there would be interregional variations in the cost of a windpump.

575o (p. 149, #8)

Technically, there are two areas of research that may prove to be fruitful in the long run. Through a lack of science combined with a lack of measuring equipment, windpump design in the past was largely empirical. So the designs have by and large *tended to be suboptimal and now through comparatively minor modifications, the* performance of some machines could be significantly improved.

576o (p. 149, #9)

A second area of research lies in matching rotors with pumps wherever reciprocating pumps are being used. There are two mismatches between rotors and pumps. The first mismatch results from the fact that power available from a rotor is proportional to the cube of the wind speed whilst the power requirement of the pump varies only linearly with its speed. The second mismatch arises from the cyclic torque requirement of piston pumps in which starting torque in the first stroke is three times the average torque required. Whilst the first mismatch requires research on pumps where the speed better matches the power available, the second mismatch requires research on methods of reducing the starting torque.

577o (p. 149, #10)
Although wind electric pumps are potentially more efficient than wind mechanical systems, their track record so far has been quite limited. They, however, offer the advantage of higher heads, can be located away from the water sources at better wind locations, and can also be used for charging batteries.

2. Human Energy

578o (p. 150, #1)
Human energy is perhaps the most important aspect of energy in developing countries; certainly, if it is excluded, the significance of energy studies would greatly diminish. But it is also an area in which research has been least useful in terms of understanding or policy. The difficulty arises in the measurement of human energy itself.

579o (p. 150, #2)
In economics, the concept that comes nearest to the human energy is the number of workers. The potential number of workers is termed labour, the number that is actually working is termed employment, and the number of workers who are not employed is called unemployment. In the 1930s, when a large proportion of the workers was unemployed in industrial countries, an explanation of unemployment was offered by Keynes (1936). In developing countries, the problem often arises, not from the complete unemployment of people who are willing to work, but from occasional or partial unemployment. This phenomenon was termed disguised unemployment by Joan Robinson. A number of conceptual variations was observed and explanations offered (Turnham and Jaeger, 1970; Todaro 1981). But empirical estimates in terms of the number of workers remained too approximate in terms of intensity of work to be of use in energy research.

580e
An improvement in the concept is constituted by measurements of time utilization; it permits a closer study of the phenomenon of work. Much evidence on time utilization is collected in the course of anthropological studies (Carlstein et al. 1978a,b,c). Recently such evidence has been used by Carlstein (1983) to refine the concept of carrying capacity. It has also been used as a proxy for work loads within families (Tinker 1984). Time utilization has also become a subject of interest to sociologists (cf. Szalai et al. 1972) and economists (cf. Winston 1982). However, time utilization studies imply that the energy expended per unit of time is constant, which is manifestly not the case.

581o (p. 151, #4)
Differences in energy intensity of work have been known to physiologists for long; one of the most systematic efforts to quantify them was made by Passmore and Durnin (1955). Since then numerous estimates of energy expenditure per unit of time have been made in a large variety of circumstances, and been used to calculate energy balances for human beings (e.g., Thomas 1973).

582o (p. 151, #5)
The idea that the cost of work in terms of food could vary was put forward by Leibenstein (1957). He assumed that the efficiency with which a worker converted food into physical work is low when he is severely undernourished, increases as the standard of nutrition improves, then falls, and reaches a point when an increase in his food intake will not raise his work output. This relationship, known as the work-efficiency mechanism, has been used extensively in economic theory (Bliss and Stern 1978). But it had no basis in physiology until Sukhatme and Margen (1982) argued that there were systematic variations in human energy efficiency in physical activity. More recently, Borrini and Margen (1984), in a paper written for us, have given considerable evidence of variations in human energy efficiency, and have questioned the validity of mechanical models of human energy balance. Their views are strongly contested by other physiologists.

583o (p. 151, #6)

We observe that the entire subject of the physiology of human energy is one of considerable theorizing without accurate enough measurement to test the theories, and of voluminous empirical work without testing theories. In the circumstances it may be that more accurate measurements of the human metabolism reacting to variations in work, nutrition and ambience may lead to more definite hypotheses. At any rate, it seems clear that investment in further empirical work in this area without greater clarity in theory can only lead to waste.

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Meanwhile, the role of human energy in production systems remains central to development problems. We cannot stress too much the importance of research in this area, but feel that theoretical innovation is necessary for a more thorough understanding of how human energy is used or underutilized in socioeconomic activities.

XI. ENVIRONMENTAL AND HEALTH EFFECTS

585o (p. 172, #1)

As we indicated at the outset, energy production and consumption can be subject to strong externalities, which must be a major concern of policy and hence of research. Large energy projects can have very disruptive and destructive effects on the lives of people. For instance, the disruption of local livelihood patterns by big dams is well known, and has stopped or delayed hydroelectric development in many developing countries. These and other issues will be of great local concern, and will call for site-specific research.

586o (p. 172, #2)

However, there are a great many such issues, and this is not the place to deal with them in any great detail. Here we shall limit ourselves to three global issues that have caused considerable concern in industrial countries, namely acid rain and the greenhouse effect, and deforestation and desertification. Finally we shall pull together certain health effects in developing countries which have influenced our views.

1. Acid Rain

587o (p. 173, #1)

The fact of acid rain admits no doubt any longer. Its mechanism of causation does, but the role of combustion in this mechanism is also fairly firmly established although its precise degree of significance is not.

588o (p. 173, #2)

Normal rain is slightly acid; the dissolution of atmospheric carbon dioxide in rain water makes its normal pH about 5.60-5.65. This value will vary somewhat from region to region, and can be below 5.6 in regions where the atmosphere lacks alkaline materials (Canada 1981; Harte 1982; Haines et al. 1983).

589o (p. 173, #3)

However, rain (precipitation -- rain and snow -- to be precise) has become noticeably more acid in some parts of North America and Western Europe, and its increased acidity shows associaton with some serious deterioraton of flora and fauna: in particular, the destruction of certain species of common forest trees, and the disappearance from the lakes of acid-sensitive fish like trout and salmon. The H^+ ions in acid rain are believed to disrupt the mineral element cycle in plants because they displace minerals from leaves and from soils and inhibit their acquisition by plant roots. It is possible that increasing acidity of rain increases the uptake by plants of toxic substances like cadmium, and the intake of mercury in fresh water fish; however, this latter correlation is not yet fully understood. There is also no direct evidence yet of the effects of acid rain on human beings (Taylor 1980).

590o (p. 173, #4)

The tolerance of vegetation to specific toxicants varies widely among species, and frequently among different varieties of the same species (Taylor 1980). The extent to which acid rain affects ecosystems also depends on the buffering capacity of soils. For instance, where soils and lake water are alkaline, acid rain may have little effect, but elsewhere the same increase may alter the soil balance and convert essential nutrients into forms that cannot be absorbed by plants (Haines et al. 1983).

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591o (p. 174, #5)

Acid precipitation is primarily due to the emission of sulphur dioxide, hydrogen sulphide and nitrogen oxides into the atmosphere, which react with water to form sulphuric and nitric acid. Sulphur dioxide emissions are mainly traced to (i) the combustion of sulphurous fuels and (ii) volcanic eruptions; the former emissions are estimated to be more than twice the latter (Table 13). Any high-temperature combustion process leads to the formation of nitrous oxides by the reaction of atmospheric oxygen and nitrogen. But most of the NO_x emissions come from the decay of biomass. They can also be formed by the breakup of nitrogenous fertilizers (Chamberlain 1981).

TABLE 13

Worldwide sources of SO_2, H_2S and NO_x emissions[a]

	Emissions				
	Anthropogenic	Natural	Total	Atm concentration	Residence time
	(thousand tonnes)			(ppb)	(days)
SO_2	207 000	100 000	307 000	0.2	4-8
H_2S	34	200 000	200 034	0.2	1-2
NO	48 200	391 000	439 200		
NO_2	small	598 000	598 000		
NH_3	3 600	1 054 000	1 054 600		
N_2O	small	536 000	536 000		

[a] These estimates refer to the early seventies. The estimates of emissions from natural sources may err by a factor of 2 or more.

Source: Chamberlain (1981).

592o (p. 175, #6)

By virtue of their volume, NO_x emissions play a critical role in acid rain formation through direct oxidation of nitric acid as well as precursors to the formation of strong oxidants such as hydrogen peroxide and ozone. NO_x emissions exceed SO_2 emissions. Most of the NO_x emissions, being from natural causes, are of global distribution, and probably account for the acidity of normal rain. Local adaptations to acidity abound. However, the destructive effects of acid rain have been observed mainly in North America and in Western Europe, and been correlated with SO_2 emissions.

Research

593o (p. 175, #7)

A crucial research weakness seems to be the understanding of atmospheric chemistry of acid precipitation. Though a number of numerical models exist, the large number of adjustable parameters makes it difficult to say whether the predictive success of a model is a reflection of its accurate chemistry or not. In terms of the degree of understanding of atmospheric reactions, the best understood reactions at present are the homogeneous gas phase reactions, followed in a descending order by aqueous phase reactions ("droplet" chemistry), heterogenous reactions and catalytic reactions.

594o (p. 175, #8)

Two broad areas of research that would help in understanding the chemistry of acid precipitation better are -- (a) understanding the NO_x-VOC (volatile organic compounds) cycle and its influence on the OH and HO_2 concentrations, and (b) understanding the role of HO_x radicals.

595o (p. 176, #9)

The OH (hydroxyl) radical is an important gas phase (i.e., outside the cloud and rain) reactant for both SO_2 and NO_x. Hydroperoxyl radical (HO_2) is essential for the formation of hydrogen peroxide (H_2O_2) -- a very strong oxidant for SO_2 in cloud and rain droplets. Many chemists believe that the liquid phase oxidation of SO_2 may be the dominant pathway for producing sulphuric acid. Finally, NO_2 itself is oxidized by the OH radical to HNO_3 (Chamberlain 1981; Shaw 1984).

596o (p. 176, #10)

Understanding the two phenomena mentioned above has direct consequences for the strategies of abatement of acid rain. The main sources of HO_x are ozone photodissociation and formaldehyde. In both cases, NO_x is a basic raw material (although formaldehyde formation begins with the presence of hydrocarbon radicals in the atmosphere). Thus, if NO_x in the atmosphere could be reduced, this would reduce the HO_x concentrations and may, therefore, lessen both major sources of acidification by diminishing the nitric acid directly and the rate of aqueous oxidation of SO_2 to sulphuric acid. A reduction in the rate of oxidation of SO_2 would have a greater probability of allowing it to be absorbed as a gas on the ground thus reducing acidified precipitation. Some fraction of ground absorbed SO_2 would nonetheless be converted to sulphate by oxidants including O_2. In effect then, a reduced rate of oxidation of SO_2 in the atmosphere may not do away with all the adverse impacts of acid deposition but it would alter its geographic distribution and probably also the nature of its effects.

Abatement

597o (p. 176, #11)

The height of stacks has gone up from an average height of 200 ft. in 1960 to 600 ft. in 1981 in North America (Chamberlain 1981). But this cannot be seen as part of an abatement strategy. Tall stacks reduce local pollution but greatly increase the chance of pollution at a distance (Postel 1984).

598o (p. 177, #12)

"Liming" of lakes to reduce their acidity must be seen as strategy which focuses on alleviating damage at the receiving end (i.e., downwind areas) rather than controlling emissions at source (United States of America 1984). It is a temporary palliative at best because decreasing the acidity does not put the leached metals back into the rocks.

599o (p. 177, #13)

Thus abatement strategies, if they are to be successful in the long run, must focus on emission reduction techniques. In the case of SO_2, they consist of the following -- (a) coal washing, (b) "scrubbing" the flue gases in older power plants,

(c) switching to lower-sulphur fuels, and (d) using limestone injection multistage burners (LIMB). (a) is not very cost-effective at present for lower-sulphur content coals and (d) is only under early stages of development in the USA and under commercial demonstration in the Federal Republic of Germany (United States of America 1984).

600o (p. 177, #14)

Control of emissions of oxides of nitrogen is more difficult than control of SO_2. NO_x can currently be controlled by changing the rates and proportions at which air and fuel are mixed in a combustion process. But not all utility boilers can be retrofitted with combustion modification equipment. In any case, this would reduce the emissions only by about 25 per cent. For higher levels of control, changes in furnace geometry may be required. NO_x can also be removed through flue gas treatment and reduced through LIMB.

601o (p. 177, #15)

If the use of small scale coal combustion units (e.g., stoves) increases in a particular area, then high nitric acid concentrations are likely to be a major local problem. In such cases, research on coal stove combustion efficiency and NO_x emission control would be especially important (Harte 1982).

602o (p. 177, #16)

Those developing countries which have high concentrations of fossil fuel and biomass combustion and a large land mass, such as China, India and Brazil, have an interest in the study of the acidity of the rainfall and any correlations it shows with vegetation and fauna. If such correlations are found, acid rain abatement may be as relevant to them as to industrial countries.

2. The Greenhouse Effect

603o (p. 178, #1)

If acid rain is a catastrophe whose cause is under debate, carbon dioxide buildup is a cause looking for a catastrophe.

604o (p. 178, #2)

Precise monitoring of CO_2 concentration in the atmosphere began at the Mauna Loa Observatory in Hawaii in 1958. Whilst measurements became much more common in the seventies, data from direct observations are generally sparse and short-range. However, indirect observations can be made on the basis of the composition of vegetation (cf. Stuiver 1978). They suggest that atmospheric concentration of CO_2 was 265-290 ppmv (parts per million by volume) in 1860 (Rotty 1983a). In 1975 it was 333 ppmv in Hawaii, and the trend there was clearly upwards since 1958 -- a trend confirmed by observations elsewhere over shorter periods. Unlike acid rain, which is observed to be localized downwind from centres of fossil fuel combustion, CO_2 concentration appears to vary much less across the world.

605o (p. 178, #3)

All carbonaceous fuels including coal, oil, synthetic fuels and biomass fuels generate CO_2 on combustion; the CO_2 generated depends on their carbon content. Per 100 quads (105 EJ) of energy, natural gas produces 1.45 gigatonnes, oil 2 Gt, coal 2.5 Gt and synthetic fuels 3.4 Gt. From these figures it has been estimated that CO_2 emissions from fossil fuels were 150 Gt between 1860 and 1975; in that period, the rise in CO_2 concentration in the atmosphere amounted to 95-148 Gt (Woodwell 1974).

606o (p. 178, #4)

However, the destruction of biomass, whether by decomposition or combustion, also releases CO_2. CO_2 concentration in the atmosphere shows regular annual cycles which are believed to be due to the seasonal accumulation and destruction of terrestrial biomass. The conversion to agriculture of what used to be forest lands is believed to have reduced the terrestrial stock of biomass. Its effect is much more difficult to quantify, but the resulting CO_2 emissions are estimated to be 75-150 Gt over 1860-1975. These, together with emissions from combustion, suggest total emissions of 170-298 Gt. CO_2 in the atmosphere is estimated to have risen by

105 Gt in the same period. Thus if biomass decomposition and carbon consumption were the only sources, 35-66 per cent of the releases actually accumulated in the atmosphere. The question is: where did the rest go? One possibility is that it went into the sea, where too organic matter is always accumulating and decomposing; but whether it did or not is very uncertain.

6070 (p. 179, #5)

The difficulties are threefold. First, the stocks of carbon and its compounds in the atmosphere, on land and in the seas are so large compared to the annual flows between them, that small changes in the rates of change of the stocks can generate very large variations in the flows. Second, the only flow for which there are reasonable estimates is of releases from fossil fuel combustion into the air; all other estimates are extremely uncertain (Fig. 2).

6080 (p. 179, #6)

Third, if recently advanced hypotheses are correct, the prediction of the greenhouse effect is based on a seriously misspecified model. A recent study by Ramanathan et al. (1985) claims that the influence of other trace gases, especially fluorocarbons, ozone and nitrogen compounds, may warm global climate much more than (1.5-3.4 times as much as) carbon dioxide alone. If this were the case, the causes of climatic change may be much more diverse than fuel combustion. Further, the magnitude of the warming effect of carbon dioxide release has also been contested by Somerville (Yulsman 1985), who claims that CO_2 buildup will make clouds denser and more reflective, and will reduce the quantum of solar energy entering the atmosphere.

6090 (p. 179, #7)

Despite these refinements, it is likely that the present models of global climate are extremely partial. Contrary to the predictions of the CO_2 effect, global temperature has not been rising; on the contrary, it has fallen since the 1940s.

6100 (p. 179, #8)

Thus our knowledge of the greenhouse effect, and of the determinants of climate in general, is yet primitive. But the implications of climatic change are as serious (though not the same) for developing countries as for industrial countries, and developing countries have an interest in keeping a watching brief on the research as well as in participating in it.

3. Deforestation and Desertification

6110 (p. 181, #1)

The logical chain from domestic firewood combustion through deforestation to desertification, though never fully argued through in literature, has taken such hold on popular imagination that it needs to be seriously addressed.

6120 (p. 181, #2)

Firewood consumption: The available estimates simply do not serve as a basis to judge the nature and the seriousness of the problem. Smil (1983:81-83) gives estimates ranging from 1.3 to (his own) 3.2 billion m^3/year, and conversion factors ranging from 0.15 to 0.8 t/m^3. The uncertainties extend in three directions: (a) per capita fuel consumption varies enormously; (b) its composition varies not only from place to place and family to family, but for the same family over the seasons, in adjustment to fuel supply and need; and (c) most of what we know comes from energy consumption surveys, which are generally silent on the origin of the fuel -- whether

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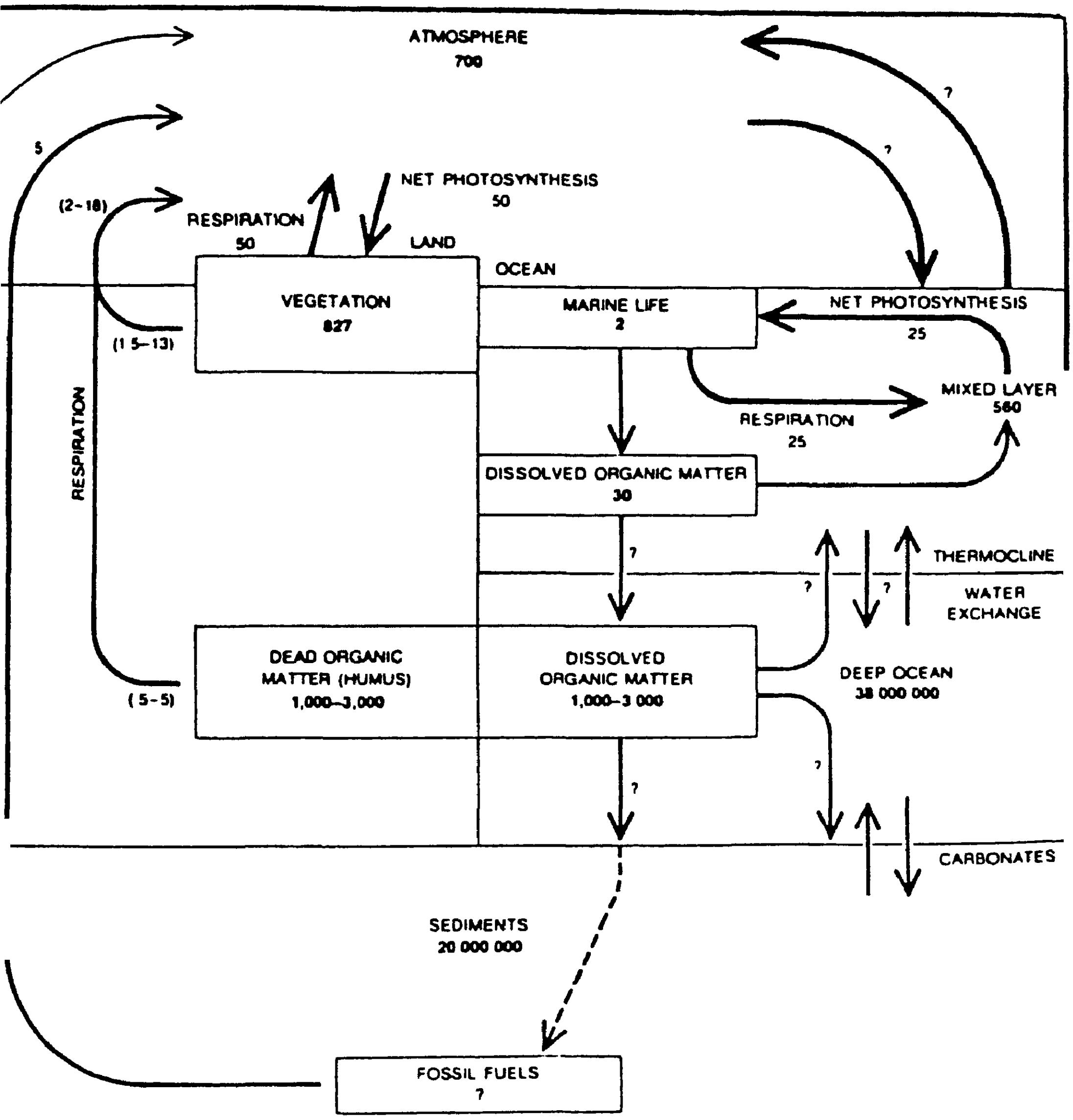

Fig. 2. Global pools and flows of carbon. Pools are expressed in billions of metric tons of carbon, flows in billions of metric tons of carbon per year (Source: Woodwell 1978).

it came from trees at all or from crops; if from trees, whether it was harvested from trees or obtained by destroying trees; and whether it was the main product or the byproduct of another activity like timber supply. It is quite important to distinguish between fuel coming from natural annual biomass accretions and other biomass fuel. That people burn part of the annual increments is just as bad, for instance, as they eat or drink a part of them and use the energy in respiration.

613m AK

Deforestation: Deforestation is a strictly regional problem, and is to be encountered in two types of situations, namely where land is being cleared for agriculture, as in Brazil and Indonesia (both of which are exporting wood to industrial countries), and where strong demand in nearby urban centres uses up wood for two main purposes, namely construction and combustion; for instance, in Nepal, parts of China and parts of Africa. This effect of strong urban and industrial demand leading to deforestation is not unknown in industrial countries: it occurred around the Mediterranean in Roman times, in Britain and Europe as early as the 18th century, in the United States in the 19th century, and is going on even now in Canada and the USSR. It may cause concern on a number of grounds: scientific (for instance, the destruction of tropical forest species), aesthetic (for instance, the ugliness of deforested landscapes), or economic (for instance, erosion may cause flooding or reduce land productivity; destruction of forests may deprive forest-dependent populations of livelihood; deforestation may lead to desertification). But it is important to discuss deforestation in a regional context, for the reasons for deforestation, the reasons for concern, and the remedies will be different in different regions. If this is done, it will be found only seldom that the remedy for deforestation is reafforestation; for, as with desertification which we discuss below, cheaper and more effective solutions can be found to specific problems created by deforestation.

Desertification

614o (p. 182, #4)

Insofar as it has occurred, desertification is not the creation of new deserts in what were vegetation-rich areas in recent history, but an extension of what have been deserts for a few thousand years. The connexion between climate and deserts is palpable; and the connexion between climatic change in the last 4000-6000 years and desertification is also fairly well established (Kellogg and Schneider 1977). However, whilst the desertification has been local and incremental, climatic change has been global; the climate all over the world is dryer and cooler than 4000-6000 years ago. Long-term evidence does not support the thesis that desertification caused climatic change.

615o (p. 182, #5)

Two mechanisms have been suggested through which removal of vegetation cover leads through a reduction of rainfall to desertification:

> "Where vegetation in an arid zone is not degraded, there is always a diffuse ground cover of at least 20 to 40% of perennial species such as shrubs, undershrubs, and perennial grasses. This is enough to protect the soil surface from erosion; or, more precisely, wind erosion in these conditions is compensated by sand deposited behind the obstacles that perennial plants constitute.
>
> "Where the distance between two perennial species is equal to or longer than five times their height, deflation is no longer compensated by sand deposition and erosion increases up to the point where the whole land surface is covered by pebbles or stones after removal of all movable material. The sand that drifted away accumulates in barkhans, reboubs, nebkas, sand veils, and the like. This sand drift takes place over rather short distances, seldom surpassing a few hundred meters and then up to no more than a few

> kilometers. The final result is that soil layers, which used to be superposed as sandy or loamy deposits over rock outcrops or limecrusts, become juxtaposed as a result of wind erosion. Permanent plant life then becomes impossible, for the lack of water reserves in the shallow soil of the reg prevents seedlings from surviving the first prolonged drought period. In shifting sand, perennial species, too, cannot get established. Just as soon as the seedlings have emerged, they are uprooted and blown away."
> (Le Houérou 1977: 20)

Here, what is referred to is vegetation, not trees; the natural vegetation of arid regions is shrubs and perennial grasses, and not trees.

616m WS

The second cause that has been suggested is an increase in albedo and a reduction in vegetative debris through overgrazing. An increase in albedo reduces the warming up of land and the formation of convective plumes that bring rain bring rain (Charney et al. 1975). Rain formation is facilitated by the presence of ice-forming nuclei in the clouds. Among the sources of such nuclei are microflora and bacteria from decayed leaf litter, whose production would vary with the ground vegetation (Schnell and Vali 1976; Vali et al. 1976). Thus it may well be that a reduction of vegetation cover tends to reduce rainfall owing to lower production of ice-forming nuclei (Kellogg and Schneider 1977).

617o (p. 184, #8)

Among the remedial measures, students of desertification place afforestation quite low. It can have no significant effect on the regional climate, and would require subsequent management and organization (Le Houérou 1977). A remarkably large number of remedial schemes have been proposed for the Sahara (Glantz 1977a). Of them, one is proven: Egypt and Pakistan are standing evidence of the efficacy of irrigation in desert areas. Another -- cloud seeding -- has been often tried but not evaluated. More speculative and exciting schemes have proposed asphalt belts (spraying a large area with asphalt to reduce albedo); seeding clouds with carbon dust to absorb solar radiation, to heat up the surrounding air and to increase evaporation from the oceans; and flooding the Sahara by means of a canal from the Mediterranean. On a social scale, a number of alternatives have been suggested including control of overgrazing (Kellogg and Schneider 1977), concentration of development in a few better-endowed areas, and urbanization and industrialization (Ware 1977).

618o (p. 184, #9)

The problems of the desert areas have been brought to the fore by the Sahelian famine. We are sure that the solutions are not clear; but we are sure that singling out bivariate relationships like that between deforestation and desertification is a misspecification of a complex of relationships, and if used as a basis for policy, can lead to much waste of resources.

4. Health Effects

619o (p. 185, #1)

The interconnections between energy and health are so diverse that we could not survey it with any degree of thoroughness (cf. Centre for Science and Environment 1982). Here we would confine ourselves to pointing out three areas in which our view of energy research has been strongly influenced by its implications for health.

620o (p. 185, #2)

(i) We are impressed by the evidence of health hazards from traditional biomass-burning stoves in developing countries (Smith and Ramakrishna 1984). This has not been the subject of serious research, and we are sure that more systematic

investigations are called for. But more complete combustion to reduce carbon monoxide emissions as well as the reduction of particulate emissions are of obvious importance to the health of cooks, almost all of whom are women. This is one of the reasons for the stress we have placed on charcoal development.

621o (p. 185, #3)

(ii) Whilst we do not regard nuclear power as safe, we recognise the weight of the argument that coal mining is a dangerous and unhealthy industry. This is shown by evidence from industrial countries (cf. Ramsay 1979; Clifford and Mead 1984); it is reasonable to think that the coal industry is at least as hazardous and unhealthy in developing countries. This is why we have regarded coal production as an exception to our general preference for labour-intensive and employment-generating technologies. We regard coal mechanization as a life- and health-saving measure.

622m AK WS

(iii) Solar distillation of water is not likely to find wide application; once the demand for water exceeds a certain threshold, it is cheaper to purify it by conventional methods. But in many villages it does not and is not likely to reach that threshold. Where diarrhoeal diseases are endemic, solar distillation presents a cheap way of purifying small quantities of drinking water; they have the additional advantage of eliminating other impurities such as salts and heavy metals as well. This is why we have given some importance to solar distillation.

XII. CONCLUSIONS

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This report is about developing countries. This is a generic term which hides many differences -- differences whose implications it has been beyond the resources of this project to pursue. Yet, when energy research priorities have to be determined, this decision will generally be faced at the level of a developing-country government, or at the even more micro level of a producer or a research institution. For these decision-makers, this report does not offer a recipe. But it offers, in the first place, a menu -- a taxonomy or a mapping of the energy issues that a developing country may face. And in the second place, it offers an approach, let us say the beginnings of a methodology, for determining priorities in research aimed at solving national problems. Let us recapitulate what seem to us to be the essential features of such a methodology.

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Policies are made and decisions reached much more often than research is done to inform them. To be useful, research must improve upon uninformed decisions. But if research is to improve decisions, three conditions have to be met.

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(i) **Research capacity:** Researchers must be capable of suggesting more and better alternatives than unaided decision-makers. Amongst many other things, this involves resources, exposure and interaction. Researchers must have resources -- libraries, laboratories, instruments, access to information -- that would raise their results above casual observation. They must be exposed to empirical and policy problems. And finally they must form a large enough group, and must interact amongst themselves actively enough, to stimulate one another and to eliminate one another's errors.

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(ii) **A long perspective:** A researcher is distinguished by high standards for reaching conviction; he looks more deeply into causes than a layman, and subjects evidence to a stricter scrutiny. For this reason, research takes time to yield results. The time lags in the application of research can be reduced insofar as problems are anticipated by researchers. Nevertheless, decision-makers have to recognize the fact that research takes time, and to adapt decision-making processes to this fact. Decisions must themselves become a part of the learning process.

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(iii) **An integrated approach:** A part of the researcher's task is to look beyond the proximate causes to the more remote and less obvious interconnections. This implies that research-based policies would also have a wider range.

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These three features are the preconditions for the workability of a research-policy nexus. It is in the context of such a nexus that it becomes meaningful to set research priorities. Where such a nexus exists, the priorities emerge from the steps required for research to make an effective contribution to policy.

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The **first** step consists of research into the interconnections between energy and the rest of the economy. This research should lead to the establishment of reliable relationships between nonenergy activities and the demand for energy.

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The **second** step consists of research that uses this understanding of the energy economy to project energy demand and supply and to identify in advance the likely imbalances facing a country or a region. Policy variables will inevitably enter into these projections, and it is important that socioeconomic objectives, such as those relating to income distribution, should be incorporated into the projections.

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The **third** step consists of research into the optimum ways of removing the imbalances, which may consist of alternative ways of increasing the supply or reducing the demand for energy. The research may relate to the development of new forms of energy, the improvement of technologies, cost reduction, quality improvement, energy saving or interfuel substitution. But all these types of studies should be viewed in the context of the **uses** of energy and the optimum choice among the alternative ways of serving a use.

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Where there is no effective research-policy nexus, the first two steps will be missing, and priorities will have to be fixed among micro-level research proposals without an overall framework in which they can be fitted. Even in these circumstances, a simple judgment of priority or nonpriority can be based on whether a particular alternative is or promises to be the most economic way of serving a use.

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ARGENTINA

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PEOPLE'S REPUBLIC OF CHINA

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GLOBAL ENERGY MODELS

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Whilst projections only spell out the future implications of existing or assumed tendencies, in recent years they have been used to study the implications of realized or impending discontinuities. All the discontinuities that have formed the starting point of recent global energy models have been in the nature of catastrophes. Thus the models have a strong element of firefighting: explicitly or implicitly, they are normative models, and each of them stresses a few instrumental variables.

645n JG

The first such major model, that of the Workshop on Alternative Energy Strategies, took the prospect of oil exhaustion as its starting point. It conceived of the ensuing problem as one essentially of changing the fuel mix: it could be solved if:

"nearly all fossil fuels were removed from use in electric power plants, to reduce processing losses;

"synthetic crude oil is made from available coal supplies, in order to meet essential demands for liquid fuels; and

"industrial and domestic sectors use significantly more coal and less electricity than currently and preferred plans" (Wilson 1977).

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In other words, the Workshop on Alternative Energy Strategies advocated a shift from oil to coal and nuclear power. The International Institute for Applied Systems Analysis envisaged an even faster decline of oil consumption, and hence a faster shift to other fuels. It was also sceptical of the feasiblity of a rapid build-up in nuclear capacity. Hence it leant in favour of a larger increase in coal production up to 2000 than WAES did. After 2000, however, physical constriants on coal output led IIASA to advocate more rapid increase in nuclear capacity; its projected energy mix for 2030 was thus not very different from that suggested by WAES for 2000 (Hafele et al. 1981).

647n JG

The International Energy Agency's projections involve a similar shift towards coal and nuclear power by 2000 for OECD countries. They involve a larger shift towards coal and a smaller one towards nuclear than those of WAES; they are thus closer to those of IIASA (International Energy Agency 1982b).

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In association with the IEA projections, the Oak Ridge Institute of Energy Analysis made projections of implicit CO_2 emissions; however, since the greenhouse effect is expected to become serious later than IEA's terminal date of projections, the projections were extended to 2050. As will be seen from Table 14, the projections of Edmonds and Reilly (1983a) are similar to those of IIASA for 2000. By 2050, however, extrapolation on the same set of assumptions leads to considerably larger energy consumption estimates, and hence to requirements of coal and nuclear energy. Edmonds and Reilly's projections of oil supply look too high if oil depletion curves are to be believed; in which case their estimates of the growth of coal output and nuclear power also would be too low. On the basis of their model they concluded:

649n JG

"Simple time trend extrapolations of the post-war rate of growth of CO_2 release yield a doubling window between 2021 and 2035. Our base case no surprises scenario yields a doubling window period of 2049-2067. This finding indicates a doubling date as much as three decades later than scientists had originally used as a reference point" (Edmonds and Reilly 1983b).

TABLE 14

Some recent global energy consumption projections

(Exajoules)

Source	Coverage	2000	2025	2030	2050	Oil	Natural gas	Nuclear	Hydro	Coal	Other
1. WAES	WOCA[a]	436				204	61	62	26	75	8
1977		364				161	47	86	19	47	4
2. IIASA	World	531				186	98	209	26	156	10
1981		428				150	80	40	26	124	8
				1124		215	188	255	46	378	41
				706		158	109	163	46	203	26
3. IEA	OECD[b]	243				102	35	26	-[c]	73	22[d]
1981		213				82	40	24	-[c]	62	14[d]
		230				77	43	27	-[c]	78	21[d]
4. Edmonds	World	485				154	82	40	57[e]	152	-
and Reilly			921			183	113	158	118	350	-
1982					1646	301	89	363	119	747	27[d]

Notes:
[a] "World outside communist areas"

[b] Member countries of the Organization for Economic Cooperation and Development

[c] Included in "other"

[d] Includes hydro

[e] Includes solar electric

Sources:
1. Workshop on Alternative Energy Strategies: Wilson (1977)
2. International Institute for Applied Systems Analysis: Hafele (1981)
3. International Energy Agency (1982b)
4. Edmonds and Reilly (1983a).

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However, Edmonds and Reilly also recognize that the strategy favoured by IEA (as also IIASA) only postpones the rise in CO$_2$ levels, and does not avoid it. Other Oak Ridge researchers have similarly worked out the CO$_2$ implications of IIASA projections and come to conclusions which call for a greater sense of urgency (Perry et al. 1982). In their view, it may be necessary to keep the ultimate global CO$_2$ level below 800 ppmv and perhaps below 500 ppmv. If this is to be done, a shift away from the combustion of fuels, and especially of fossil fuels, would have to start within the next few decades, possibly as early as 2010 and probably by 2040. This implies a rise in the use of renewable energy sources, especially of the noncombustive ones. But their maximum feasible potential in the next century is no more than 250-315 EJ. This means that the total global energy consumption must be subjected to an absolute limit, and that any growth of incomes should be achieved within that limit. In other words, growth should be based on increasing energy efficiency -- on energy conservation.

651n JG

This is the starting point of the study of Goldemberg et al. (1985). Given the fact that fossil fuels are nonrenewable, they must be replaced by renewable energy eventually. Meanwhile, the use of fossil fuels gives rise to a number of undesirable externalities, of which the rise in atmospheric CO$_2$ is only one. The approach of other researchers has been to advocate the continuation of high levels of fossil fuel consumption in the coming decades while technological solutions to the attendant environmental problems are developed. The approach of Goldemberg and his colleagues, on the other hand, is to seek to eliminate those problems themselves, by working towards a supremely energy-efficient world.

HIERARCHICAL MICROCOMPUTER-BASED MODELLING FOR INTEGRATED NATIONAL ENERGY PLANNING (INEP), POLICY ANALYSIS AND MANAGEMENT

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National energy models have been developed in many countries for various purposes ranging from specific policy studies to purely academic purposes (Devezeaux 1984, Munasinghe 1985). However, most of these efforts have been in the industrialised countries. The purpose of this appendix is to provide an illustrative example of how a state-of-the-art microcomputer-based energy modelling framework was built in a developing country (Sri Lanka), to meet the local needs for integrated national energy planning (INEP), policy analysis and management. This country case study provides valuable insights of a more general nature into the practical problems of formulating and implementing energy policy. Since the modelling effort is only a part of the broader sweep of energy sector activities, it is relevant to begin with some background information before discussing details of policy analysis and planning.

1. Sri Lanka Energy Background

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Significant progress has already been made over the past few years towards the development and implementation of a national energy strategy (NES) in Sri Lanka. More specifically, in late 1982, the President of Sri Lanka appointed a Senior Energy Advisor to supervise a new energy coordinating team (ECT), consisting of three task forces, to strengthen energy policy formulation and coordination and overcome problems due to the dispersed nature of the energy sector institutional framework. The task forces were: (1) Energy Planning and Policy Analysis (EPPAN); (2) Energy Demand Management and Conservation (EDMAC); and (3) New, Renewable and Rural Sources of Energy (NERSE). Several important programmes with obvious short-term benefits were quickly identified by the ECT, and launched in late 1982 and early 1983: (a) the National Energy Demand Management and Conservation Programme (NEDMCP), aimed at promoting greater efficiency in the production and use of the major commercial fuels (oil, electricity and gas) in all sectors of the economy; and (b) the National Fuelwood Conservation Programme (NFCP), to introduce more efficient domestic cookstoves. Among other short-term initiatives, the national power utility -- the Ceylon Electricity Board (CEB) -- has embarked on a loss-reduction programme, and the Ceylon Petroleum Corporation (CPC) is about to build a facility that will decrease the cost of oil imports by reducing transportation expenses.

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These programmes, whilst clearly yielding short-term benefits, are essentially of a one-time nature. They will reduce energy consumption over the short- to medium-run, but even if completly adopted throughout the economy, cannot arrest the longer-term trends -- as development proceeds and the economy and population increase. In brief, the NEDMCP and NFCP are essential to immediately reduce energy costs, but they must be followed up with supporting initiatives within the framework of a systematic and consistent long-run national energy strategy.

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Over the medium- to long-term, therefore, some of the more fundamental issues must be addressed. In contrast to many other developing countries that nature has endowed with significant fossil resources, the prospects for discovering similar resources in Sri Lanka remain poor. In such a situation, not only are the energy options more limited, but also the failure to adopt a comprehensive, long-term strategy is much more severe. Otherwise, the ever-increasing resources needed for power investments and oil imports will result in severe foreign exchange difficulties, resulting in the dampening of economic growth. Moreover, continuing deforestation will also have severe adverse consequences.

656n MM
In recognition of these longer-term problems, the EPPAN of the ECT was charged with the identification of the major objectives and issues of national energy policy and the definition of a national energy strategy over the longer term. The modelling framework described below helped to produce the NES, which can be updated quite easily at regular intervals. The NES integrates and consolidates the many aspects of the short-term programmes already begun with the options for the medium- to long-term, and outlines the long-term policy for the country.

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In brief, the models are designed to reflect the actual conditions in the country as closely as possible, and the analytical framework is specifically tailored to facilitate quick and accurate responses to the types of questions a senior decisionmaker might pose. All the basic model calculations were first verified using simpler manual methods, and the computerized framework was developed only after local staff capability and experience, as well as confidence in the approach, had been built up.

658n MM
The models are implemented on a 256 kilobyte, 16-bit, MS-DOS compatible microcomputer, with two floppy disk drives, and a 10 megabyte hard disk (optional). An optional high resolution, colour screen and printer, greatly improve the graphics, and the ability to more clearly and effectively convey important results to senior policymakers. Most of the models are written in Fortran enhanced by Assembly language routines, while Lotus 1-2-3 is used for many data analyses and for file manipulation.

2. The Analytical Methodology

659n MM
The analytical approach is illustrated in Figure 3, which is the modelling analogue of the conceptual framework shown in Figure 1 (Chapter 2). The process begins with an analysis of the overall macroeconomy in the first of three modules of the ENMAC macroeconomic accounting framework. The outputs of this step include projections of the sectoral decomposition of GDP and nonenergy merchandise trade.

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The RESGEN energy model is run next. The demand equations in this model are driven by the GDP estimates passed from the macromodel. Other inputs are passed from the more detailed sectoral models: the refinery configuration and yield coefficients are drawn from the refinery optimization model, and the estimates of fuelwood demand are taken from the fuelwood model. As part of making the energy supply-demand balance, RESGEN estimates which energy facilities must be built to meet the demand, thereby providing a year-by-year estimate of investment requirements. The basis for the electric sector investments, which account for the bulk of the total energy investment, is the generation plan of the CEB, derived from subsector planning models such as WASP and PROBSIM. Because different demand scenarios result in changes in the future electric load growth, the analysis includes an examination of the timing of capacity increments. An optimal dispatch model built into RESGEN also provides detailed estimates of CEB fuel consumption as a function of plant availabilities, hydro energy limitations and the system load factor.

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The investment outlays, and their concomitant debt service obligations, are passed back to the ENMAC macromodel, together with the oil import bill (and the smaller earnings from bunkers and petroleum product exports). These energy sector transactions are merged with the nonenergy transactions in a second module of ENMAC. Finally, the third module provides overall estimates of the balance of payments, the financing necessary to cover the external resource gap, the debt service ratio, and other macroeconomic impacts.

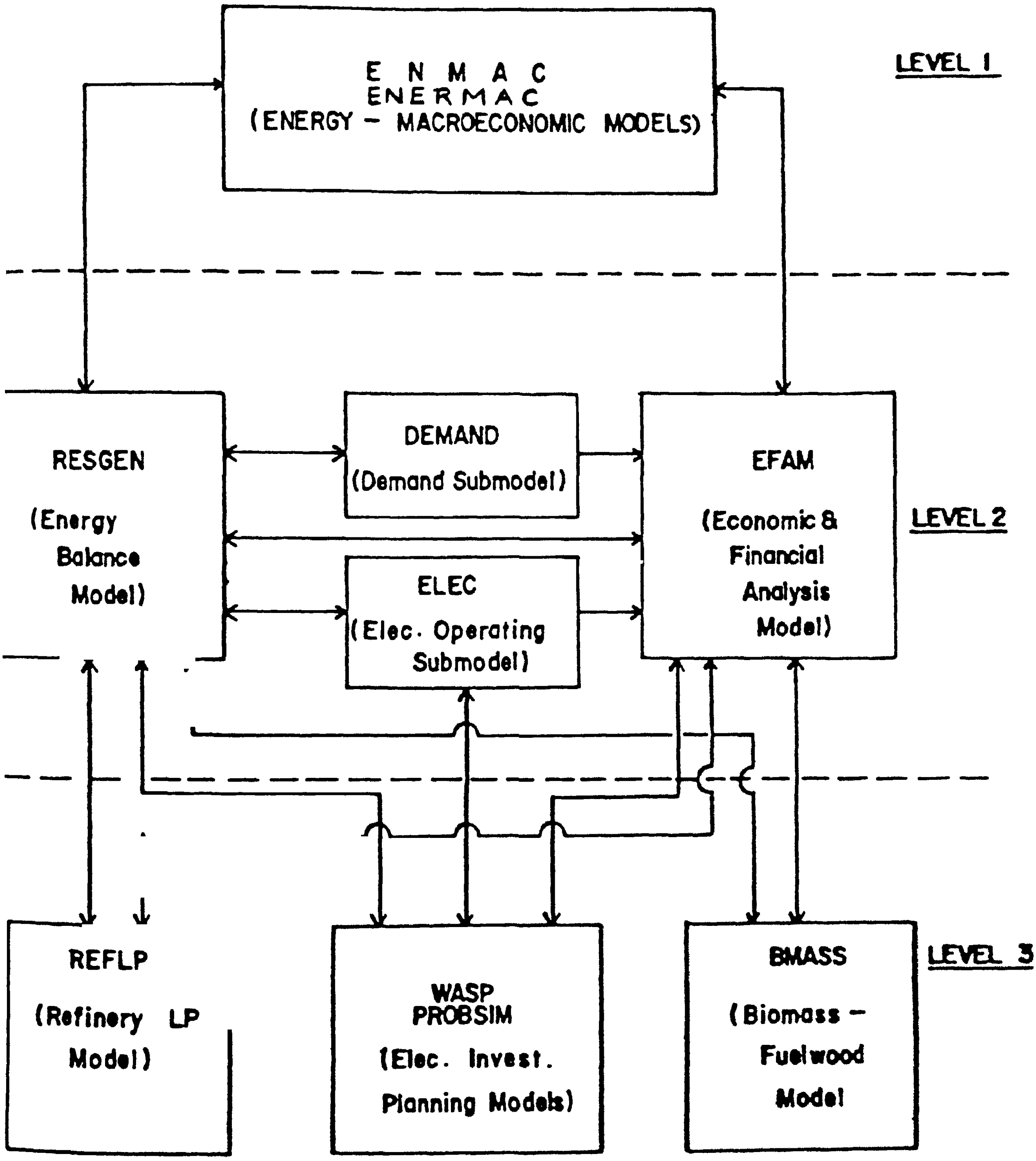
E N M A C
ENERMAC
(ENERGY - MACROECONOMIC MODELS)
LEVEL 1
RESGEN
(Energy Balance Model)
DEMAND
(Demand Submodel)
ELEC
(Elec. Operating Submodel)
EFAM
(Economic & Financial Analysis Model)
LEVEL 2
REFLP
(Refinery LP Model)
WASP
PROBSIM
(Elec. Invest. Planning Models)
BMASS
(Biomass - Fuelwood Model
LEVEL 3

Fig. 3. Hierarchical computer modeling framework for integrated national energy planning in Sri Lanka

662n MM

The RESGEN energy model passes the domestic energy transactions (e.g., sales from the CPC to the distributors, or CEB sales to consumers) to the Energy Finance Assessment Model (EFAM), which assembles a picture of the energy sector financial flows among the key institutions and consumers in the sector. EFAM also provides estimates of the government revenue from the sector (from petroleum product taxes, the Business Turnover Tax on Energy Institutions, customs duties, etc.). The financial flows are obtained by multiplying the physical energy flows (from RESGEN) by the appropriate set of prices and taxes; EFAM can therefore be used to assess the implications of alternative energy pricing and taxation schemes.

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Another more sophisticated multisector energv-macroeconomic model (ENERMAC) is also available to study wage, income and price effects, factor substitution in production, structural change, etc. ENERMAC has a transactions matrix involving ten goods/sectors, including three energy-producing sectors, crude oil imports, and six energy-consuming sectors (Munasinghe et al. 1985). The model produces a set of national accounts and balance-of-payments consistent with the corresponding outputs generated by ENMAC, as well as equilibrium wages and prices. The economv grows through sectoral investments, and appropriate sector-specific production functions are used to produce sectoral outputs, as the model simulates year by year into the future. ENERMAC is not fully linked to the other models, but used in parallel, as a complement, to study specific policv impacts in a self-consistent manner.

The Scenarios

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The methodology adopted for this study is to superimpose the policy options that lie under the control of the Sri Lanka government on to a series of scenarios that capture the key external factors over which the decisionmaker has no control. Among the most important of these external factors are the world oil price, the overall state of the world economy that determines the external trade environment, and such factors as the level of interest rates on the external debt. Because of the dependence of the electric sector on hydroelectricity, rainfall variations represent another important source of uncertaintv.

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(i) **Economic growth:** Ideally, one would wish to project the domestic economic growth rate as a function of domestic policy and the external environment. However, the present state of the art of macroeconomic modelling is such that great difficulties are still encountered in quantifving some of the key relationships. Indeed, the experience of Sri Lanka since the economic liberalization of 1977-1978 disproves much of the common wisdom concerning the short-term impact of external shocks, and oil price increases in particular, on the rate of economic growth.

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Therefore, the domestic growth rate is used as one of the exogenous assumptions of the analysis. Three scenarios of GDP growth are assumed over the period 1985-1995, ranging from a high case of 5.5 per cent GDP growth through 1995, to a low case of 3.5 per cent growth to 1990, falling to 2.5 per cent in the early 1990's.

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The base case assumes a 5.5 per cent growth from 1984-1988, which is consistent with the projection of the Ministry of Finance and Planning (MFP) in its last annual report on public investment. From 1989 to 1995 it is assumed that the rate falls to 4 per cent per year. This scenario implies a continuation of the growth trend over the past 7 years since the economic reforms were introduced by the incoming administration in 1978. Even though this trend was maintained during a period of

severe external shocks -- the oil price increase of 1979-1980, sharp increases in the price of imported goods due to worldwide inflation -- as well as falling world market shares of the international tea and rubber trades, growth rates in the late 1980s in excess of this trend are most improbable. We do examine a case, however, in which the 5.5 per cent rate is maintained through the mid-1990's.

668n MM

There are, however, a number of reasons for the GDP growth rate to be substantially less. There is no guarantee that Sri Lanka's significant growth in manufactured exports will continue, which together with the increasing external payments burden, may begin to cause dislocations in the economy. The low scenario therefore posits a GDP growth rate of 3.5 per cent to 1990, falling to 2.5 per cent in the period 1989-1995. It should of course be noted that these scenarios are not in the nature of forecasts or predictions; they are used in this study for the sole purpose of examining the consequences of energy policy options under different sets of conditions, defined for the policy analysts by senior decisionmakers.

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(ii) **Oil price:** The future condition of the world oil market is extremely difficult to foretell. Moreover, the complexity of the market, with the intricate interactions between the prices of different crudes and petroleum products, further complicates the situation for a small importing country such as Sri Lanka. Even without some cataclysmic disruption to the world oil supply situation, the next 5 years will bring significant changes to the petroleum product market in Southeast Asia, as the new refineries in the Persian Gulf come on stream. Therefore, although the landed price of crude is used as the index of world oil price, it may be seen that the interplay of petroleum product prices around this level has implications for Sri Lanka of the order of millions of dollars per year.

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In the high world oil price (WOP) case, we assume constant real prices until 1988, followed by an annual increase of 4 per cent thereafter (again in real terms). This brings the 1995 real price to about the levels experienced at the very peak of the oil crisis in the early 1980s. (The 1984 average c.i.f. crude oil price in Colombo was $214 per tonne). The low WOP case assumes constant real prices until 1989, with a 1 per cent per annum real price increase thereafter. Again it should be stressed that these scenarios are used for indicative purposes only, and no judgement is made as to which of these scenarios is more likely. Indeed, the entire thrust of the national energy strategy is the identification of policy initiatives that are robust (i.e., relatively unaffected) under the expected uncertainties.

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(iii) **Hydrological uncertainties:** A national energy strategy must be concerned with short-term as well as long-term issues, of which temporary disruptions to the supply are among the most important. As Sri Lanka becomes more dependent on hydroelectricity, the ability of the Ceylon Electric Board to cope with drought years also becomes more important, since most of the major dams are concentrated in a relatively small area of the hilly country. The impact of a failure of, or delay in, the monsoon rains can be very serious. Two cases are examined: the current planning basis of the CEB that is based on the firm + 25 per cent of secondary hydro energy, and a case based on firm hydro only (that corresponds roughly to a 1 in 50 year hydrological event). It should of course be noted that there is a 1 in 5 chance that this event will in fact occur at some time over the next 10-year period. Table 15 presents the energy levels for hydro plants associated with these two cases.

TABLE 15

Energy from hydroelectric plants (GWH per year)

	Base case (firm + 25% secondary)	Firm hydro only (1 in 50 years)
Existing hydro plants	1597	1508
Victoria	767	695
Kotmale	368	315
Randenigala	390	366
Broadlands	95	86
Rantembe	185	156

The Analytical Design

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The analytical design for the model runs in shown in Figure 4. In constructing the overall scenarios one obvious issue is the degree to which the world oil price and GDP assumptions are correlated. Increases in the oil price are only one of several types of external shocks that Sri Lanka has exprienced (and will experience in the future); and the adjustment mechanisms to these external shocks can be quite complex (Munasinghe 1984a). Thus it is not possible to forecast a direct impact on GDP from a given oil price shock (as the experience of Sri Lanka in the years 1977-1982 reflects very well). Indeed, the impact of the relative ease with which Sri Lanka was able to adjust to the shocks of the 1970's, of which additional external financing was a major part, will only now be felt as the debt service obligations become due. For the same reason, the fact that oil prices are currently falling in real terms does not necessarily imply a faster domestic growth rate.

673n MM

Given these circumstances, the basic modelling design is structured around the four possible combinations of oil price and GDP growth. In the case of the electric sector analysis, we also include the hydro-energy uncertainties. We superimpose a series of cases that reflect the policy interventions under consideration onto these basic scenarios that capture the exogenously-determined factors. These include initiatives for energy conservation, electric sector demand management, pricing, fuelwood plantation and cookstove programmes, refinery management and oil import strategies, fuel substitutions and others. The details of these strategies are presented below.

3. Major Problems and Policy Issues

(i) Fuelwood Consumption and Deforestation

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The absence of a long-term policy to arrest the present rate of deforestation leads to dramatic and possibly irreversible impacts by the mid-1990's. Our estimates indicate that from fuelwood consumption alone (i.e., ignoring other

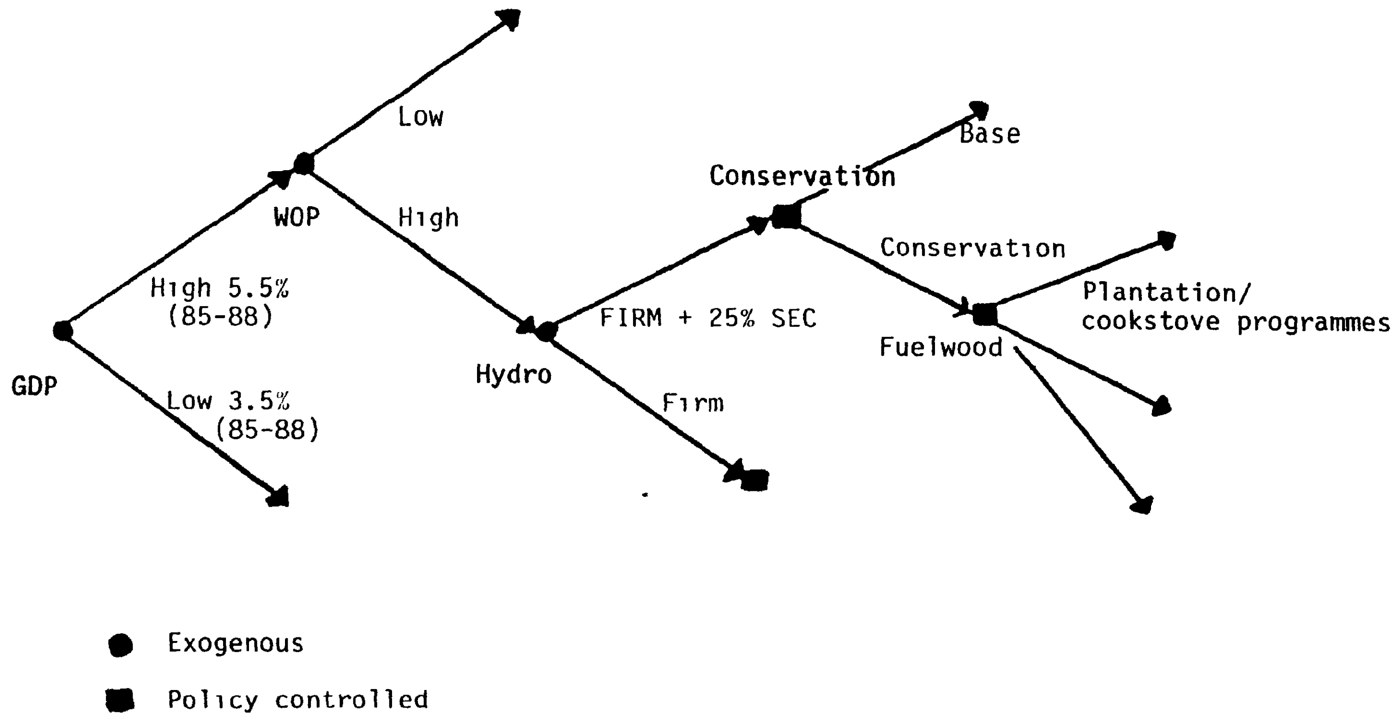

Fig. 4. Model runs

factors such as construction timber demands), the forest cover will decline from about 1.6 million ha (or 24% of total land area) today, to 0.3-0.5 million ha (or well under 10% of land area) by 1995, depending on assumptions about the sustainable yield. Obviously, at these levels of resource depletion, sharp price increases for fuelwood can be expected -- leading in turn to possible substitution by expensive, imported petroleum products.

(ii) Oil Imports and the Balance of Payments

675n MM

As a result of the oil price shocks of the 1970's, by 1982 net oil imports accounted for 50 per cent of export earnings, compared with 6 per cent in 1970. This trend will pose a continuing strain on the balance of payments for the forseeable future. Whilst the recent decline in real oil prices (denominated in dollars) has provided some relief, past experience indicates that this is not a permanent condition. Moreover, even at current oil prices, we estimate that the oil import bill will reach $580 million by 1990, accounting for 27 per cent of merchandise export earnings under the latest macroeconomic scenario of the MFP (up from $419 million in 1984).

(iii) Energy and Macroeconomic Development

676n MM

As noted in the recent MFP report for the 1985-1989 period, over the longer term, economic performance will be strongly influenced by the ability to redress the fundamental problems in the balance of payments. Import substitution in agriculture, and continued emphasis on export-oriented industrial development, are identified as the keys to achieving longer-term balance. However, neither of these sectors is particularly energy intensive. Therefore, to the extent that targets for these sectors are not met (for example due to protectionist measures against textile imports to the USA or Europe), slower domestic growth will not be accompanied by significant declines in the oil import bill. The model results show that in the slower GDP growth scenario (i.e., growth rate declining to 3.5% by 1990, rather than maintaining the expected level of 5.5%), the oil import bill is still of the order of $550 million by 1990, and accounts for 32 per cent of export earnings (compared with 27%, if GDP growth can be maintained at 5.5%).

(iv) Investment and Debt Service

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Energy sector investments, particularly for power, are expected to increase substantially over the next decade. Of the new public sector projects for the period 1986-1989, the power sector will account for almost two-thirds. Moreover, debt service obligations, particularly of the CEB, are expected to rise significantly over the next few years. By 1990, energy sector debt service is expected to be about $135 million, as opposed to about $35 million in 1985. Moreover, the CEB investment programme will require significant amounts of as yet unidentified foreign capital. As many other countries have already experienced, the ability to attract such financing is related to the overall balance of payments situation and credit-worthiness of the economy, which is expected to worsen over the next few years -- thereby making it more difficult for the CEB to obtain foreign financing.

(v) Vulnerability to Drought

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As seen in 1983-1984, drought conditions have a number of severe impacts. Oil dependent thermal generation (to substitute for electricity) places even more burdens on the balance of payments. In cases of severe drought, load curtailments may be necessary. As the CEB system becomes more dependent on hydroelectricity (1990's), and because the catchment areas are concentrated in a relatively small geographic area, the impact of droughts also becomes relatively more significant.

4. Energy Policy Options and Initiatives

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In the light of these fundamental problems, the basic directions of energy policy are clear. Indeed, as noted earlier, vital and correct policy initiatives have already been launched in several areas. Based on these general directions, the following broad policy options have been identified whose impacts are examined in more detail in subsequent sections.

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Increasing the efficiency of energy use: Increasing energy efficiency is not merely for short-term benefit but must be pursued consistently over the longer term. Lacking its own fossil resources, for the next 30-40 years the bulk of Sri Lanka's energy must come from imported fuels, until sometime in the 21st century when newer energy technologies will replace fossil fuels. Without a sustained effort to maximize the efficiency of fossil fuel utilization, development objectives will inevitably be compromised.

681n MM

In a similar vein, those domestic resources that are available must be utilized more effectively. The forest resource is a priceless asset upon which the bulk of the population still depend for their basic energy needs. Unless fuelwood is used more efficiently, the long-term consequences will be catastrophic.

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Therefore, the NEDMCP and NFCP must be expanded rapidly and pursued vigorously by the EDMAC and NERSE task forces in collaboration with other concerned institutions.

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Pricing policy: Recent changes in electricity and oil prices have brought average commercial fuel prices close to economically efficient levels (i.e., border price). These favourable trends must be maintained to ensure good demand management. While average prices are reasonable, the detailed structure of electricity and oil prices need to be further revised -- especially prices of kerosene and diesel relative to gasoline.

684n MM

Reducing the vulnerability to external shocks: Over the past decade Sri Lanka has experienced numerous external shocks affecting both the energy sector and the economy as a whole, particularly the two oil price shocks of the 1970's and the 1983-1984 drought. In order to reduce this vulnerability, diversification of both the type and source of energy is vital. Increasing coal use for power generation and industrial energy, purchasing petroleum products and crude from a variety of sources (including the spot market) will decrease vulnerability, as well as cost.

685n MM
Maximizing domestic resources: Hydroelectricity and fuelwood represent the country's two main domestic fuels. Even if commercial oil finds are made in the next few years, and even if the efforts to commercialize other renewable energy technologies -- small hydro, producer gas, wind, solar heating, etc. -- are successful, until the year 2000 conventional hydro and fuelwood will be the main sources of domestic energy.

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Institutional framework: Prior to 1983, the institutional framework was fragmented with the various energy sector line institutions like CEB, CPC, Forest Department, NARESA, Mahaweli Development Authority, etc., all reporting to different ministries. As mentioned earlier a number of reforms were made in late 1982. The ECT was set up to formulate and coordinate policy. This mechanism is working well with each of the three task forces EPPAN, EDMAC and NERSE responsible for one major programme (NES, NEDMCP and NFCP, respectively), as well as many smaller initiatives. This framework should be maintained and strengthened.

687n MM
More recently, the Lanka Electricity Company was created as a subsidiary of the CEB gradually to take over electricity distribution, and the CPC was absorbed within the Ministry of Power and Energy -- further consolidating policy coordination and implementation in the commercial fuels sector. The NES should be implemented using the framework of the ECT for overall coordination, and the line agencies -- for implementation.

Specific Initiatives

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Based on these general directions, we have analysed a series of policy options in some detail using the analytical framework available to the Energy Coordinating Team (ECT).

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Fuelwood sector initiatives: Whilst the NFCP is clearly essential, it must be recognized that even an aggressively-promoted cookstove programme does not address the long-term problem, as already noted. Indeed, our analysis shows that the breathing space afforded by NFCP over the next few years must be used to put in place a plantation programme of at least 10000 ha/year, in addition to the programmes already under way (the latter provide for only about 5000 ha/year). The long-term foreign exchange consequences of a depleted forest resource are extremely serious, quite aside from the impact on rural families whose household budgets would then have to cope with the cost of commercial fuels. In 1985, fuelwood is estimated to have provided some 4.3 million tons of oil equivalent of energy: even when one takes into account the much higher efficiencies at which petroleum utilizing devices operate, this still represents an avoided foreign exchange cost of $200 million.

690n MM
Conservation initiatives: A comprehensive programme of conservation initiatives, encompassing electricity as well as petroleum products in the transportation and industrial sectors, is of high priority. This will have long-term as well as short-term benefits. If the present goals of the NEDMCP are met (Table 16), the savings on the aggregate oil import bill by 1990 are estimated as shown in Table 17.

TABLE 16

NEDMCP conservation goals

	1990 % saving	Equivalent annual impact on growth rate of demand
Electricity (2)		
Domestic	5	-1.0%
Large industry (1)	10	-2.0%
Small + medium industry	10	-2.0%
Commercial	10	-2.0%
Local authority	5	-1.0%
Petroleum products		
Auto-diesel	10	-2.0%
Gasoline	10	-2.0%
Fuel oil	10	-2.0%

(1) In addition, the conservation scenario assumes implementation of the industrial projects identified in the recent World Bank prefeasibility studies over the period 1987-1989.

(2) The CEB loss reduction programme is included in the base case.

TABLE 17

Impact of the NEDMCP - Oil import savings ($ million)

	1988	1992
Base case GDP growth	$25.3	$56.0
Low GDP growth	$24.9	$49.5

691n MM
The conservation programme is therefore seen to provide substantial benefits independent of both the state of the world oil market and the actual rate of economic growth. The conservation programme also serves to cushion the impact of droughts, as shown in Figure 5. Under the current capacity expansion plan of the CEB, attainment of the electricity conservation targets reduces oil consumption to very low levels even in drought years.

692n MM
Renewable initiatives: The NERSE task force has been established to coordinate the development of a variety of renewable energy sources. Whilst some of these technologies appear promising, a concerted effort will be necessary to establish coherent implementation. To examine the scope of the impact of such efforts, an optimistic scenario for the penetration of these technologies into the economy is assumed (Table 18).

TABLE 18

Maximum renewables case

	Basis	1995 GWH
Mini + micro-hydro	15 Mw by 1995	39
Wind	5 Mw by 1995	26
Producer gas	1 150 Kw unit/year	5
Solar water heaters	30000 panels in place, 6 Kwh equiv/day	21
Photovoltaics	10000 panels in place	8
Biogas	5000 systems, 1.8 Kwh/ day	11

693n MM
Even under these rather optimistic assumptions, our analysis indicates that these technologies would displace only 2 per cent of CEB's 1995 generation, with a decrease in the oil import bill of 1 per cent.

694n MM
Pricing policy: The importance of maintaining a petroleum product pricing system based on the foreign exchange cost to the country has been examined, by simulating the energy system under alternative price elasticity assumptions (Table 19). Case 1 assumes that retail prices will stay at their current levels in real terms: the impact on oil consumption (and the oil import bill) is simulated by assuming zero price elasticity of demand. Cases 2 and 3 reflect different levels of price response to the increases in the real oil price in our base case scenario.

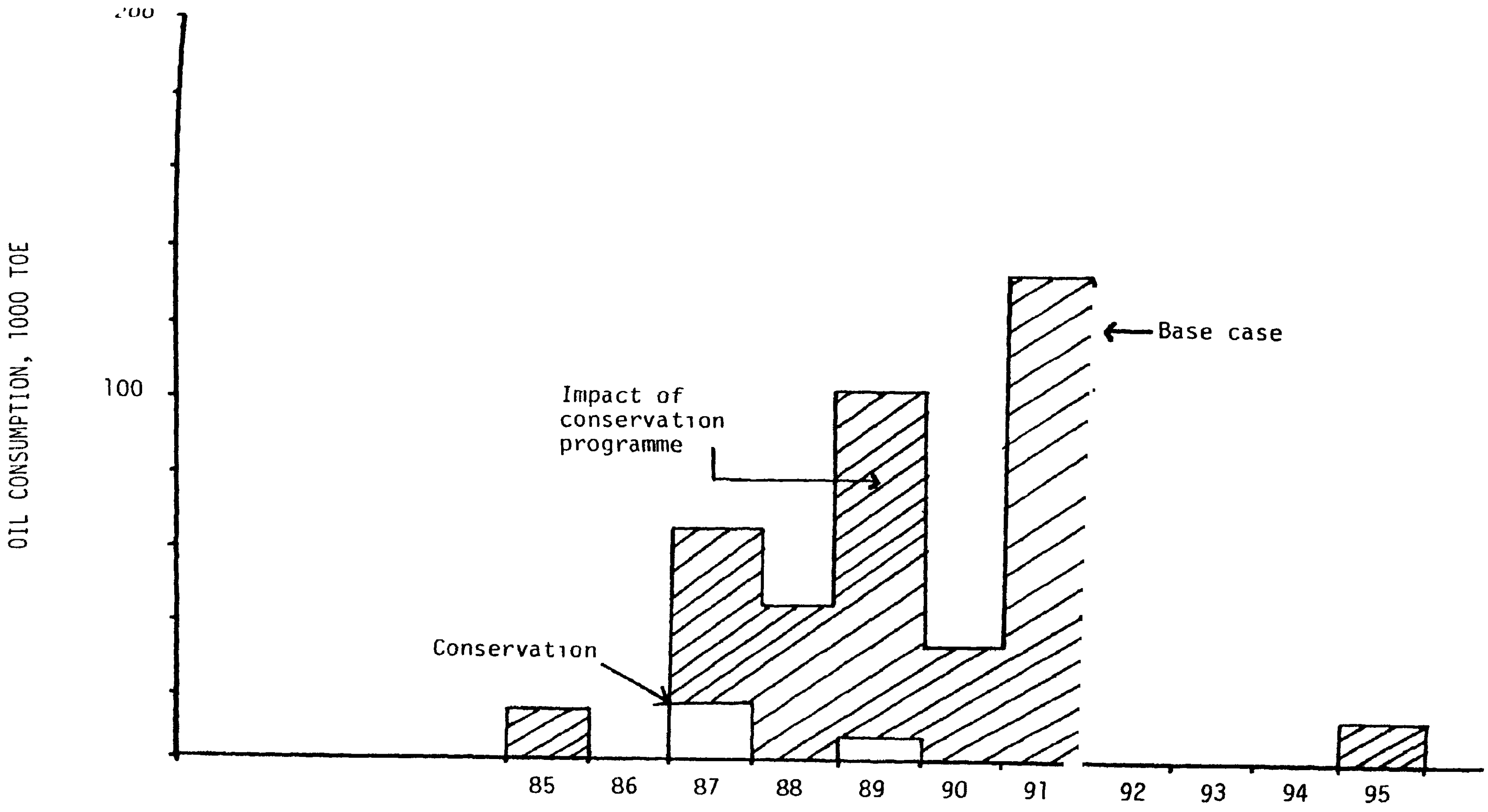

Fig. 5. Impact of the conservation programme on CEB oil consumption

TABLE 19

Impact of petroleum product pricing policy

	Oil imports (1000 toe)	Foreign exchange ($m)
1. No price adjustment	2678	625
Prices adjusted to border price		
2. = -0.15	2594	596
= -0.3	2517	568

695n MM
These results indicate the serious consequences of any failure to maintain domestic retail prices consistent with border or economically-efficient prices.

5. **Summary and Conclusions**

696n MM
In order to examine the impact of various energy policy options in Sri Lanka, a hierarchical microcomputer-based modelling framework has been developed locally that provides a consistent basis for integrating the planning assumptions of the different institutions involved in the energy sector, and enables the impact of specific policy initiatives to be examined over the medium to long term. These models have been successfully used to develop the NES.

697n MM
At a macroeconomic level, this framework involves an energy-economic accounting model and a macroeconomic multisector model that are aligned to the planning process at the Ministry of Finance and Planning -- this makes the energy sector analysis consistent with the overall directions of national development, and permits the analysis of the macroeconomic impacts of energy sector policies. At the intermediate level, there are an energy balance model and an energy financial analysis model that integrate the analysis within the energy sector. At the lowest or subsectoral level, a series of detailed models for the fuelwood sector, for the CPC refinery, and the electric sector, allows us to integrate the detailed work performed by the individual line institutions (Forest Department, CPC, CEB).

698n MM
The approach has been to define a number of scenarios that reflect the external conditions faced by Sri Lanka, and over which the country has no control: (1) the world oil price; ((2) the general state of the world economy (and its specific dimensions, such as interest rates and the state of world trade, that strongly affect Sri Lanka's economy); (3) the rainfall, etc. Specific policy responses, such as conservation, are then superimposed on these scenarios in order to examine how well they remedy and mitigate the adverse consequences of the external shocks.

699n MM
One of the main lessons of the past decade is that longer-term planning must allow for significant levels of uncertainty. Therefore, no attempt has been made to precisely forecast the future, and then define a national strategy based on that prediction. Instead, the goal is to identify those strategies and policy options that provide the greatest flexibility and effectiveness over a wide range of uncertainties, and those that will lessen the country's vulnerability to external shocks.

REFERENCES

Adelman, M.A. (1985): An unstable oil market. **The Energy Journal** 6(1)17-22.

Advisory Committee on Technology Innovation (1977): **Methane generation from human, animal and agricultural wastes.** National Academy of Sciences, Washington, D.C.

Alam, Manzoor et al. (1985): Fuelwood use in the cities of the developing world: Two case studies from India. **Natural Resources Forum** 9(3)205-213.

Alston, L.L. (1984): **Railways and energy.** World Bank Staff Working Papers, No. 634. World Bank, Washington, D.C.

Anandalingam, G. (1983): **Policy incentives for industrial energy conservation.** TERI Discussion Paper No. 2. Tata Energy Research Institute, New Delhi.

Anandalingam, G. (1984): **Energy conservation in the industrial sector.** Energy Research Group, Ottawa.

Apte, P.C. (1983): Substitution among energy and non-energy inputs in selected Indian manufacturing industries: An econometric analysis. **Indian Economic Journal** 31(2)71-90.

Asian Development Bank (1984): **Compilation of technical assistance activities in the energy sector of Asian Development Bank's developing member countries.** Asian Development Bank, Manila.

Auer, P. and D. Douglas (ed) (1983): **Advances in energy systems and technology, volume 4.** Academic Press, New York.

Aureille, R. (1984): Deux siécles de production d'hydrogène. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V,** Vol. 1, Pergamon Press, New York, 21-46.

Backus, C.E. (1984a): Principles of photovoltaic conversion. In G. Furlan et al. (ed) (1984): **Nonconventional energy.** Plenum Press, New York. 297-348.

Backus, C.E. (1984b): Photovoltaic technology assessment. In G. Furlan et al. (ed) (1984): **Nonconventional energy.** Plenum Press, New York. 349-386.

Baier, M. (ed) (1985): **Energy and economy: Global interdependencies. Volume 5: Technologies and supply options for developing countries.** Papers presented at the Seventh Annual International Conference of the International Association of Energy Economists, Bonn, June 3-5, 1985. International Association of Energy Economists and Gesellschaft fur Energiewissenschaft und Energiepolitik, Bonn.

Barnett, A. (1978): Biogas technology: A social and economic assessment. In A. Barnett et al. (1978): **Biogas technology in the Third World: A multidisciplinary review.** IDRC-103e. IDRC, Ottawa.

Barnett, A. et al. (1978): **Biogas technology in the Third World: A multidisciplinary review.** IDRC-103e. IDRC, Ottawa.

Beale, W.T. (1981): Stirling engines for developing countries. Draft of article published in National Academy of Sciences (1981): **Supplement: Energy for rural development: Renewable resources and alternative technologies for developing countries.** National Academy Press, Washington, D.C.

Bechtel National Inc. (1979): **Handbook for battery energy storage photovoltaic power systems.** Bechtel, San Francisco.

Becker, Gary S. (1981): **A treatise on the family.** Harvard University Press, Cambridge.

Behrens, Alfredo (1984): Energy and output implications of income redistribution in Brazil. **Energy Policy** 12(2)110-116.

Beijer Institute (1983): **Producer gas 1982: A collection of papers on producer gas with emphasis on applications in developing countries.** Beijer Institute, Stockholm, Sweden.

Ben Daniel, D.J. and E.E. David Jr. (1979): Semi-conductor alternating-current motor drives and energy conservation. **Science** 206(4420) 773-776.

Berndt, E. and D. Wood (1975): Technology, prices, and the derived demand for energy. **Review of Economics and Statistics** 57(3)259-268.

Berndt, E. and D. Wood (1979): Engineering and economic interpretations of capital-energy complementarity. **American Economic Review** 69(3)342-354.

Berry, R.A. and W. Cline (1979): **Agricultural development: An international perspective.** Johns Hopkins University Press, Baltimore.

Bhagavan, M. and R. Carlman (1982): **Strengthening of energy research capacity in developing countries.** Swedish Agency for Research Cooperation with Developing Countries, Stockholm, Sweden.

Bhatia, R. (1983): **Planning for the petroleum and fertilizer industries: A programming model for India.** Oxford University Press, New Delhi, India.

Bhatia, R. (1984a): **Energy alternatives for irrigation pumping: An economic analysis for Northern India.** ILO Working Paper 137. International Labour Organization, Geneva.

Bhatia, R. (1984b): **Energy and agriculture in developing countries.** Energy Research Group, Ottawa.

Bhushan, B. (1984): **Energy research and development programmes in India.** Energy Research Group, Ottawa.

Bialy, J. (1979): **Firewood use in a Sri Lankan village: A preliminary survey.** Occasional Papers on Appropriate Technology. University of Edinburgh, Edinburgh, Scotland.

Bilgen, E. and K.G.T. Hollands (ed) (1985): Intersol 85: **Extended abstracts: Biennial Congress of the International Solar Energy Society, June 23-29, 1985, Montreal, Québec.** ISES/SESCI, Montreal, Québec.

Binswanger, H.P. (1978): **The economics of tractors in South Asia -- An analytical review.** Agricultural Development Council, New York and ICRISAT, Hyderabad, India.

Bliss, C. and N. Stern (1978): Productivity, wages and nutrition. **Journal of Development Economics** 5(4)331-398.

Blitzer, Charles R. (1984): Energy demand in Jordan: A case study of energy economy linkages. **The Energy Journal** 5(4)1-19.

Blitzer, Charles R. et al. (1975): **Economy-wide models and development planning.** Cambridge University Press, Cambridge.

Blitzer, Charles R. and Richard S. Eckaus (1983): **Energy-economy interactions in Mexico: A multiperiod general equilibrium model.** Working Paper MIT-EL 83-017WP. Massachusetts Institute of Technology, Boston, Mass.

Bockris, J.O'M. et al. (1985): On the splitting of water. **International Journal of Hydrogen Energy** 10(3)179-202.

Bohi, D.L. (1983): **What causes oil price shocks?** Energy and National Security Series, Discussion Paper D-825. Resources for the Future, Washington, D.C.

Borrini, G. and S. Margen (1984): **Human energetics.** Energy Research Group, Ottawa.

Bos, M.G. and J. Nugteren (1974): **On irrigation efficiencies.** Publication 19, International Institute for Land Reclamation and Improvement, Wageningen.

Brazil (1983): Ministério das Minas e Energia. **Modelo Maben -- Versão I: Metodologia para projeção de curto prazo e analise de balanços energéticos.** Brasilia.

British Mining Consultants Ltd. (1983a): **Progress Report No. 2: Operational Assistance, Mechanized Longwall Mines, Coal Sector India.** For Overseas Development Administration (U.K.), London.

British Mining Consultants Ltd. (1983b): **Report on further development of Moonidih Mechanized Longwall Training Institute and proposed scheme of training for work on mechanised longwall faces for Coal India Limited.** For Overseas Development Administration (U.K.), London.

Brooks, D. (1984): **Markets for electricity with efficient application.** Energy Research Group, Ottawa.

Brown, N. and P. Tata (1984): **Biomethanation.** Energy Research Group, Ottawa.

Bruggink, J.J.C. (1984): **The socio-economic aspects of introducing solar flat plate collector technology in the Sahel.** ILO Working Paper 130. Intational Labour Organization, Geneva.

Buchanan, M. et al. (1980): **Transport planning for Greater London.** Saxon House, Aldershot, England.

Bullard III, C.W. and R.A. Herendeen. (1975): The energy costs of goods and services. **Energy Policy** 3(6)268-278.

Bullard III, C.W. et al. (1978): Energy analysis handbook. **Resources and Energy** 1.267-313.

Caceres, A. (1985): **Combustion of wood and charcoal: Challenges to the diffusion of efficient stoves and kilns.** Symposium on Biomass Energy Systems: Building Blocks for Sustainable Agriculture, Airlie, Virginia, 29 January - 1 February.

Campbell, B. (1983): Petrodollar recycling: An explanation and evaluation of what happened from oil shock one to the present time. In R.M. Bautista and S. Naya (ed) (1983): **Energy and structural change in the Asia Pacific region: Papers and proceedings of the Thirteenth Pacific Trade and Development Conference held in Manila, Philippines, January 24-28, 1983.** Philippine Institute for Development Studies and Asian Development Bank, Manila. 447-467.

Campos, E.V. (1984): Electrolytic hydrogen -- application feasibility in Brazil. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V,** Vol. 1, Pergamon Press, New York, 313-322.

Canada (1981): House of Commons. **Still waters: The chilling reality of acid rain: A report of the sub-committee on acid rain of the Standing Committee on Fisheries and Forestry.** Department of Supply and Services, Ottawa.

Carlstein, T. (1983): **Time resources, society and ecology: On the capacity for human interaction in space and time: Volume I: Preindustrial societies.** Allen and Unwin, London.

Carlstein, T. et al. (ed) (1978a): **Timing space and spacing time: Volume 1: Making sense of time.** Edward Arnold, London.

Carlstein, T. et al. (ed) (1978b): **Timing space and spacing time: Volume 2: Human activity and time geography.** Edward Arnold, London.

Carlstein, T. et al. (ed) (1978c): **Timing space and spacing time: Volume 3: Time and regional dynamics.** Edward Arnold, London.

Carpetis, C. (1984): Break-even and optimization conditions for overall energy systems wherein hydrogen storage facilities are used. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V**, Vol. 1, Pergamon Press, New York, 233-248.

Carr, E. H. and R. W. Davies (1969): **Foundation of a planned economy 1926-1929.** A history of Soviet Russia 10. Vol. 1, Part II. Macmillan Press, London.

Casimir, H.B.G. (1983): Comment on: Paper presented by R.L. Garwin: Industrial support for research mechanisms and magnitude. In J. Kendrew and J.H. Shelley (ed) (1983): **Priorities in research: Proceedings of the Fourth Boehringer Ingelheim Symposium held at Kronberg, Taunus, 12-15 May, 1982.** Excerpta Medica, Amsterdam.

Casler, Stephen and Suzanne Wilbur (1984): Energy input-output analysis: A simple guide. **Resources and Energy** 6.187-201.

Cecelski, Elizabeth (1984): **The rural energy crisis, women's work and family welfare: Perspectives and approaches to action.** World Employment Programme Research Working Paper WEP10/WP.35. International Labour Office, Geneva.

Centre for Science and Environment (1982): **The state of India's environment, 1982: A citizen's report.** Centre for Science and Environment, New Delhi.

Chamberlain, J. (1981): **The physics and chemistry of acid precipitation.** Technical Report JSR-81-25. SRI International, Menlo Park, Cal.

Charney, J. et al. (1975): Drought in the Sahara: A biogeophysical feedback mechanism. **Science** 187(4175)434.

Chatterji, Manas (ed) (1980): **Energy and environment in the developing countries.** John Wiley and Sons, Chichester.

Chenery, Hollis B. et al. (1971): **Studies in development planning.** Harvard University Press, Cambridge, Mass.

Chigier, N.A. (ed) (1975): **Pollution formation and destruction in flames. Progress in energy and combustion science. Vol 1.** Pergamon Press, Oxford.

Chile (1982): Comision Nacional de Energia. **Balance de Energia 1961-1980 Chile.** Santiago.

Choe, B.J. (1980): Energy demand in developing countries. In J. Dunkerley (ed) (1980): **International energy strategies: Proceedings of the 1979 IAEE/RFF Conference.** Oelgeschlager, Gunn and Hain, Cambridge, Mass.

Choucri, Nazli and Supriya Lahiri (1984): Short-run energy-economy interactions in Egypt. **World Development** 12(8)799-820.

Christensen, Laurits et al. (1973): Transcendental logarithmic production frontiers. **Review of Economics and Statistics** 55.28-45.

Chung, K. (1985): **Issues of civilian nuclear technology policy in developing countries.** IDRC project: 3-A-78-4120. International Development Research Centre, Ottawa (mimeo).

Clifford, T.E. and W.J. Mead (1984): **The external costs of electric power from coal-fired and nuclear power plants.** A paper prepared for the New Delhi, India meeting of the International Association of Energy Economists, January 4-7, 1984.

Cole, D.E. et al. (1983): Future automobile engines. Paper presented at the round table discussion on "Developments in transportation fuels" at the Eleventh World Petroleum Congress, London. **Preprint of the Eleventh World Petroleum Congress, RTD 6.** John Wiley and Sons, Chichester, U.K.

Collier, H. (1984): **Developing electric power: Thirty years of World Bank experience.** Johns Hopkins University Press, Baltimore, Maryland.

Collins, R.E. (1985): Medium temperature solar thermal systems. In E. Bilgen and K.G.T. Hollands (ed) 1985: **Intersol 85: Extended abstracts: Biennial Congress of the International Solar Energy Society, June 23-29, 1985, Montreal, Québec.** ISES/SESCI, Montreal, Québec.

Commission of European Communities (1984): **Energy and development. What challenges? Which methods? Synthesis and conclusions.** Lavoisier, Paris.

Considine, D.M. (ed) (1977): **Energy technology handbook.** McGraw-Hill, New York.

Cooper, C. (1973): **Science, technology and development: The political economy of technical advance in underdeveloped countries.** Frank Cass., London.

Costanza, Robert and Robert A. Herendeen (1984): Embodied energy and economic value in the United States economy: 1963, 1967 and 1972. **Resources and Energy** 6.129-163.

Deaton, Angus (1978): **Specification and testing in applied demand analysis. Economic Journal** 88(3)524-536.

Deaton, Angus and John Muellbauer (1980): **Economics and consumer behavior.** Cambridge University Press, Cambridge.

de Cabrera, S. et al. (1982): EX-FERM ethanol production using chipped sugarcane in packed bed fermenters. European Journal of Applied Microbiology and Biotechnology **14: 21-28.**

deLucia, R.J (1984): Developing country fuel pricing policies II: A discussion of issues associated with wholesale pricing policies. **Energy Research Group, Ottawa.**

deLucia, R.J. and M.C. Lesser. (1984): Developing country fuel pricing policies I: A discussion of issues associated with retail pricing policies. **Energy Research Group, Ottawa.**

Demos, John and Sarane Spence Babcock (ed) (1978): Turning points: Historical and sociological essays on the family. American Journal of Sociology, **84, Supplement.**

Deolalikar, Anil B. and Vijverberg, Wim P.M. (1983): The heterogeneity of family and hired labour in agicultural production: A test using district-level data from India. Journal of Economic Development **8(2)45-69.**

Desai, A.V. (1978): Development and energy consumption. Oxford Bulletin of Economics and Statistics **40(3)263-272.**

Desai, A.V. (1985): Ends and means in rural energy surveys. **IDRC Manuscript Report, IDRC-MR112e. IDRC, Ottawa.**

Desai, N. (1984): Atoms for peace, atoms for war, atoms for profit. **Energy Research Group, Ottawa.**

Devezeaux, J.G. (1984): **Energy modeling in developing countries.** Energy Research Group, Ottawa.

Doniat, D. and R. Rouget (1984): Etude d'une pile alcaline H_2/O_2 pour le vehicule orbital recuperable Hermes. **Entropie** 20(116-117)79-81.

Dorado, H.J. (1985): **Strategies for cooperation in petroleum exploration and development among developing countries.** United Nations Symposium on Financing of Petroleum Exploration and Development in Developing Countries, Athens, 22-27 April 1985.

Douglas, D.L. and J.R. Birk (1980): Secondary batteries for electrical energy storage. **Annual Review of Energy** 5:61-88.

Dowdy, M.W. (1983): Advanced automotive heat engines. In R.A. Meyers (1983): **Handbook of energy technology and economics.** John Wiley and Sons, New York. 1003-1031.

Dryden, I.G.C. (1982): **The efficient use of energy.** Second edition. Butterworth Scientific Publications, London.

Dumont, R. (1957): **Types of rural economy: Studies in world agriculture.** Methuen, London.

Dunkerley, J. (ed) (1980): **International energy strategies: Proceedings of the 1979 IAEE/RFF Conference.** Oelgeschlager, Gunn and Hain, Cambridge, Mass.

Dunkerley, J. (1984): **Energy consumption patterns and their implications for energy planning.** Energy Research Group, Ottawa.

Duersten, A.L. (1983): **External financing for energy in the developing countries.** World Bank Energy Department Paper No. 8. World Bank, Washington, D.C.

Economic and Social Commission for Asia and the Pacific (1984): **Fuels for the transport sector: Compressed natural gas (CNG).** Energy Resources Development Series No. 26. United Nations, New York.

Edmonds, Jae and John Reilly (1983a): Global energy production and use to the year 2050. **Energy** 8(6)419-432.

Edmonds, Jae and John Reilly (1983b): A long-term energy-economic model of carbon dioxide release from fossil fuel use. **Energy Economics** 5(2)74-88.

Egan, J.R. (1984): Small reactors and the "Second Nuclear Era." **Energy** 9(9/10)865-874.

Egnéus, H. and A. Ellegård (ed) (1985): **Bioenergy 84: The proceedings of an international conference on bioenergy held on 15-21 June 1984 at the Swedish Trade Fair Centre, Göteborg, Sweden.** (5 Volumes). Elsevier Applied Science Publishers, Barking, England.

El Mallakh, R. (ed) (1982): **OPEC: Twenty years and beyond.** Westview Press, Boulder, Col.

El Salvador (1980: Comision Ejecutiva Hidroelectrica del Rio Lempa. **Balance energético nacional.** San Salvador.

Epremian, E. (1984): **Industrial energy management and conservation in developing countries.** Presentation at the European Congress on the Economics and Management of Energy in Industry, 2-5 April 1984. Albufeira, Algarve, Portugal.

Fein, Elihu (1982): An assessment of nonfossil hydrogen. In T. Nejat Veziroglu (ed) (1982): **Nuclear hydrogen biogas.** Ann Arbor Science Publishers, Ann Arbor, Mich., 265-282.

Fein, Elihu (1985): Hydrogen: An accommodating fuel. **International Journal of Hydrogen Energy** 10(5)281-290.

Fesharaki, F. and D. Isaak (1983): **OPEC, the Gulf and the world petroleum market: A study in government policy and downstream operations.** Westview Press, Boulder, Col.

Foley, G. and P. Moss. (1983): **Improved cooking stoves in developing countries.** Earthsran, London.

Foley, G. and Barnard, G. (1982). **Biomass gasification in developing Countries. Final report to the World Bank.** Earthscan, London.

Food and Agriculture Organization (1978): **Improved use of plant nutrients.** Report of the Expert Consultation on Better Exploitation of Plant Nutrients held in Rome, 18-22 April 1977. FAO Soils Bulletin No. 37, Rome.

Food and Agriculture Organization (1983): **Simple technologies for charcoal making.** Food and Agriculture Organization, Rome.

Food and Agriculture Organization (1984): **1983 FAO production yearbook, Vol. 37.** Food and Agriculture Organization, Rome.

Foster, J. (1985): **Petroleum exploration and development trends in the developing countries.** United Nations Symposium on Financing of Petroleum Exploration and Development in Developing Countries, Athens, 22-27 April 1985.

Freeman, C. (1982): **The economics of industrial innovation.** Francis Pinter, London.

French, D. (1985): The economics of bioenergy in developing countries. In H. Egnéus and A. Ellegård (1985): **Bioenergy 84: Volume V: Bioenergy in developing countries.** Elsevier Applied Science Publishers, Barking, England. 161-170.

Fridleifsson, I.B. (1984): **Geothermal energy exploration and utilization.** Energy Research Group, Ottawa.

Furlan, G. et al. (ed) (1984): **Nonconventional energy.** Plenum Press, New York.

Gaines, Linda L. and Alan M. Wolsky (1984): Economics of hydrogen production: The next twenty-five years. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V,** Vol. 1, Pergamon Press, New York, 259-270.

Gelin, P. and G. Petit (1980): Evolution du marché de l'hydrogène au cours des 25 prochaines années. In A.A. Strub and G. Imarisio (ed) (1980): **Hydrogen as an energy vector.** D. Reidel Publishing Company, Dordrecht, Holland, 664-674.

Georgescu-Roegen, N. (1976): **Energy and economic myths: Institutional and analytical economic essays.** Pergamon Press, New York.

Gibbons, Joel (1984): Capital-energy substitution in the long run. **The Energy Journal** 5(2)109-118.

Glantz, M.N. (1977a): The U.N. and desertification: Dealing with a global problem. In M.N. Glantz (ed) (1977b): **Desertification: Environmental degradation in and around arid lands.** Westview Press, Boulder, Col. 1-16.

Glantz, M.N. (ed) (1977b): **Desertification: Environmental degradation in and around arid lands.** Westview Press, Boulder, Col.

Goblirsch, G.M. and R.D. Talty (1980): Recent developments in fluidized bed combustion technology for lignites and subbituminous coals in the U.S.A. In the Institute of Energy (1980): **Fluidized combustion: systems and applications.** Institute of Energy Symposium Series No. 4, Volume III. Graham and Trotman, London. IA-4-1--IA-4-9.

Goldberger, A.S. (1967): **Functional form and utility: A review of consumer demand theory.** Systems Formulation, Methodology and Policy Workshop Paper 6703, Social Systems Research Institute, University of Wisconsin, Madison, Wisconsin.

Goldemberg, J. et al. (1984): **Country study -- Brazil. A study on end-use energy strategy.** Presented at the Global Workshop on End-use Oriented Energy Strategy, 4-15 June, 1984, São Paulo, Brazil.

Goldemberg, J. et al. (1985): **Energy for a sustainable world.** (2 vols.). Center for Energy and Environmental Studies, Princeton University, Princeton, N.J. (mimeo).

Gordon, A. (1984): **Guide to world coal markets.** Pasha Publications, Arlington, Va.

Grainger, L. and J. Gibson (1981): **Coal utilization: Technology, economics and policy.** Graham and Trotman, London.

Greene, R.P. and J.M. Gallagher (1980a): **World coal study: Coal -- bridge to the future.** Ballinger, Cambridge, Mass.

Griffin, J. and P. Gregory (1976): An inter-country translog model of energy substitution responses. **American Economic Review** 66(5)845-857.

Grunau, H.R. (1983): Natural gas in major basins worldwide. Paper presented at the Eleventh World Petroleum Congress, London, for a panel discussion on: World reserves of natural gas. **Preprint of the Eleventh World Petroleum Congress, PD12.** John Wiley and Sons, Chichester, U.K.

Hafele, Wolf et al. (1981): **Energy in a finite world: Paths to a sustainable future.** Ballinger Publishing Companv, Cambridge, Mass.

Haines, B. et al. (1983): Acid rain in an Amazon rain forest. **Tellus** 35B(1)77-80.

Hamakawa, Y. (1985): Recent advances in amorphous silicon solar cells and their technologies. In E. Bilgen and K.G.T. Hollands (ed) (1985): **Intersol 85: Extended abstracts: Biennial Congress of the International Solar Energy Society, June 23-29, 1985, Montreal, Québec.** ISES/SESCI, Montreal, Québec.

Hamilton, W. (1980): **Electric automobiles: Energy, environmental and economic prospects for the future.** McGraw-Hill, New York.

Harris, M. (1977): **Cannibals and kings: The origins of cultures.** Random House, New York.

Harte, J. (1982): New Developments in Acid Precipitation Research. In S. W. Yuan (ed) (1982): **Energy, resources and environment: Papers presented at the first U.S.-China conference, 7-12 November 1982.** Pergamon Press, New York.

Hartshorn, J.E. (1982): Two crises compared: OPEC pricing in 1973-1975 and 1978-1980. In R. El Mallakh (ed) (1982): **OPEC: Twenty years and beyond.** Westview Press, Boulder, Col. 17-31.

Hayami, Y. and V.W. Ruttan (1971): **Agricultural development: An international perspective.** Johns Hopkins University Press, Baltimore.

Hossain, K. (1979): **Law and policy in petroleum development: Changing relations between transnationals and states.** Frances Pinter, London.

Houthakker, Hendrik (1957): An international comparison of household expenditure patterns commemorating the centenary of Engel's law. **Econometrica** 25(3)532-551.

Howard, J.R. (1979): A technology for helping to alleviate the energy problem -- fluidized bed combustion and heat transfer. In P.W. O'Callaghan (ed) (1979): **Energy for industry: a collection of scientific and engineering papers concerned with utilising energy with maximum efficiency in industry.** Pergamon Press, Oxford. 111-129.

Howes, M. (1985): **Rural energy surveys in the Third World: a critical review of issues and methods.** IDRC Manuscript Report, IDRC-MR107e. IDRC, Ottawa.

Hudson, E.A. and D.W. Jorgenson (1974): U.S. energy policy and economic growth. **Bell Journal of Economics** 5(2)461-514.

Hughart, D. (1979): **Prospects for traditional and non-conventional energy sources in developing countries.** World Bank, Washington, D.C.

Humphreys, G.C. (1977): Methanol production and fuel methanol vs. LNG. In D.M. Considine (ed) (1977): **Energy technology handbook.** McGraw-Hill, New York. 2-120 - 2-132.

Hurst, C. (1984): **Energy for small-scale engines: A review of potential energy sources.** Energy Research Group, Ottawa.

Instituto de Economia Energética (1982): **Methodology for the evaluation of energy requirements in the developing countries** (mimeo). Bariloche.

Instituto de Economia Energética (1983): **Latin American integral energy balances -- Second report.** (mimeo). Bariloche.

Instituto de Pesquisas Tecnologicas do Estado de São Paulo (IPT) (1981): **Potencial de biomassas vegetais para fins energéticos no estado de Sao Paulo.** Companhia Energética de Sao Paulo, São Paulo.

Inter-American Development Bank (1982): **The impact of energy costs on transportation in Latin America.** IDB Economic and Social Development Department, Washington, D.C.

Inter-American Development Bank/Institute for the Integration of Latin America (1981): **Fuentes neuvas de energia situacion y perspectives de desarrollo y cooperacion -- encuesta regional.** IDB, Buenos Aires.

Intermediate Technology Power Ltd. (1983): **Wind Technology Assessment Study. Volume I. Wind Study Report.** Intermediate Technology Power Ltd., Mortimer Hill, U.K.

International Energy Agency (1979a): **Workshop on energy data of developing countries December 1978. Proceedings, Vol. 1. Summary of discussions and technical papers.** Organization for Economic Cooperation and Development, Paris.

International Energy Agency (1979b): **Workshop on energy data of developing countries December 1978. Proceedings, Vol. 2. Basic energy statistics and energy balances of developing countries.** Organization for Economic Cooperation and Development, Paris.

International Energy Agency (1982a): **The use of coal in industry.** Report by the Coal Industry Advisory Board, International Energy Agency. Organization for Economic Cooperation and Development, Paris.

International Energy Agency (1982b): **World energy outlook.** Organization for Economic Cooperation and Development, Paris.

International Energy Agency (1984): **Energy balances of developing countries, 1971-1982.** International Energy Agency. Organization for Economic Cooperation and Development, Paris.

International Labour Organization (1974): **Mechanization and employment in agriculture: Case studies from four continents.** International Labour Organization, Geneva.

International Monetary Fund (1984): **International financial statistics yearbook.** International Monetary Fund, Washington, D.C.

Ion, D.C. (1984a): **Oil and gas: Exploration and production in developing countries.** Energy Research Group, Ottawa.

Ion, D.C. (1984b): Petroleum and the developing pountries. In D.C. Ion, P.R. Odell and B. Mossavar-Rahmani (1984): **The oil prospect.** Energy Research Group Manuscript Report ERG-MR1e. ERG, Ottawa. 5-22.

Ion, D.C. et al. (1984c): **The oil prospect.** Energy Research Group Manuscript Report ERG-MR1e. Energy Research Group, Ottawa.

Isaza, José Fernando (1984): Solar energy in the tropics. In Yves Lambert et al. (1984): **Renewable energy resources.** Manuscript Report No. 3. Energy Research Group, Ottawa.

Jarass, L. et al. (1981): **Wind energy. An assessment of the technical and economic potential. A case study for the Federal Republic of Germany, commissioned by the International Energy Agency.** Spinger-Verlag, Berlin.

Jenkins, D.M. et al. (1982): **Evaluation of the ex-FERM process to UNIDO.** United Nations Industrial Development Organization, Vienna.

Julian, K. (1984): New ideas on the lead-acid battery. **Journal of Power Sources** 11(1/2)47-62.

Kahane, A. (1985): **Economic aspects of the Brazilian alcohol program.** M.A. thesis, University of California, Berkeley.

Kamien, M.I. and N.L. Swartz (1982): **Market structure and innovation.** Cambridge University Press, Cambridge.

Karch, E.G. and M. Boutette (1983): **Charcoal: Small scale production and use.** German Appropriate Technology Exchange/Deutsche Gesellschaft fur Technische Zusammenarbeit, Eschborn, FDR.

Kendrew, J. and J.H. Shelley (ed) (1983): **Priorities in research: Proceedings of the Fourth Boehringer Ingelheim Symposium held at Kronberg, Taunus, 12-15 May, 1982.** Excerpta Medica, Amsterdam.

Kellogg, W.M. and S.H. Schneider (1977): Climate desertification, and human activities. In M.H. Glantz (ed) (1977): **Desertification: Environmental degradation in and around arid lands.** Westview Press, Boulder, Col. 141-164.

Kettani, M.A. (1982): Photovoltaics in the Arab world. **Solar Cells** 6(3)239-249.

Keynes, J.M. (1936): **General theory of employment, interest and money.** Macmillan, London.

Khatib, H. (1983): **Availability of thermal generating plant in developed and less developed countries.** Paper presented to the Working Group on the availability of Thermal Generating Plant at the 12th Congress of the World Energy Conference, September 18-23, 1983, New Delhi.

Klass, D.L. (ed) (1982): **Energy from biomass and wastes, VI Symposium papers presented Jan. 25-29, 1982, Lake Buena Vista, Florida.** Institute of Gas Technology, Chicago, Ill.

Koide, S. et al. (1982): **Regional study on production of fuel ethanol from agro-products.** Economic and Social Commission for Asia and the Pacific, Bangkok.

Kristoferson, L. et al. (1984): **Renewable energy for developing countries: A review. Volume D: Solar, wind, hydro, etc.** The Beijer Institute, Stockholm, Sweden.

Kulash, Damian J. (1980): **Energy-efficient modes of transportation: Some comments on urban transportation in the United States and Latin America.** U.S. Congressional Budget Office, Washington, D.C. (mimeo).

Ladomatos, N. et al. (1978): Industrial energy use - I: Power losses in electrically driven machinery. **Energy Research** 2.179-196.

Ladomatos, N. et al. (1979): Industrial energy use - II. The prospects for providing motive power in a machine tool shop from a centralized hydraulic system. **Energy Research** 3.19-28.

Lambert, Yves et al. (1984): **Renewable energy resources.** Manuscript Report No. 3. Energy Research Group, Ottawa.

Lapillonne, B. et al. (1984): **Energy models.** Energy Research Group, Ottawa.

Laslett, Peter, assisted by Richard Wall (1972): **Household and family in past time.** Cambridge University Press, Cambridge, England.

Leach, Gerald (1976): **Energy and food production.** IPC Science and Technology Press, Guildford, England.

Leach, Gerald (1985): **Household energy handbook for developing countries. Section III: Household energy consumption.** Draft prepared for World Bank, Washington, D.C. International Institute for Environment and Development, London.

Leach, Gerald et al. (1985): **Energy and development: A comparison of 13 countries.** Final report for a Commission of the European Communities study entitled: A comparative analysis of energy demand structures of countries at different levels of economic development. International Institute for Environment and Development, London and ATW-Research, Regensburg.

Le Houérou, H.N. (1977): The nature and causes of desertification. In M.H. Glantz (ed) 1977: **Desertification: Environmental degradation in and around arid lands.** Westview Press, Boulder, Colorado. 17-38.

Leibenstein, H. (1957): **Economic backwardness and economic growth.** John Wiley & Sons, New York.

Li Jing-ding et al. (1984): Improvement in the combustion of hydrogen-fueled engines. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V,** Vol. 4. Pergamon Press, New York, 1579-1593.

Lipuma, C.R. et al. (1983): Selecting the right bottoms conversion process. Paper presented at the Eleventh World Petroleum Congress, London, for a panel discussion on: The non-residual fuel refinery. **Preprint of the Eleventh World Petroleum Congress, PD8.** John Wiley and Sons, Chichester, U.K.

Little, I.M.D. and J.A. Mirrlees (1974): **Project appraisal and planning for developing countries.** Heinemann Educational Books, London.

Lluch, Constantino et al. (1977): **Patterns in household demand and saving.** Oxford University Press, Oxford.

Long, R. (1982): **Constraints on international trade in coal.** International Energy Agency, London.

Lovins, A.B. (1977): **Soft energy paths: Toward a durable peace.** Harper and Row Publishers, New York.

Luque, A. (1984): **Photovoltaic solar electricity in developing countries.** Energy Research Group, Ottawa.

Mack, Ruth P. and T. James Leigland (1982): "Optimizing" in households, toward a behavioral theory. **American Economic Review** 72(2)103-105.

Makhijani, A. and A. Poole (1975): **Energy and agriculture in the third world.** Ballinger Publishing Company, Cambridge, Mass.

Maly, R. (1983): General prospects of improving combustion efficiency of I.C. engines. Special paper presented at the Eleventh World Petroleum Congress, London. **Preprint of the Eleventh World Petroleum Congress, SP14.** John Wiley and Sons, Chichester, U.K.

Manibog, Fernando R. (1984): Improved cooking stoves in developing countries: problems and opportunities. **Annual Review of Energy** 9. 199-227.

Martin, William F. and Frank J.P. Pinto (1979): A perspective on existing and contemplated methodologies for analysing developing country energy prospects. In International Energy Agency (1979): **Workshop on energy data of developing countries December 1978,** Vol. 1. Organization for Economic Cooperation and Development, Paris.

Martinez-Alier J. and K. Schlupmann (1985): **Energy-related issues in early economic literature: Summaries and bibliography.** Energy Research Group, Ottawa.

Mashayekhi, A. (1983): **LNG export opportunities for developing countries and the economic value of natural gas in LNG export.** Energy Department Paper No. 12. World Bank, Washington, D.C.

Mashayekhi, A. (1985): **The economic value of natural gas in residential and commercial markets.** Energy Department Paper No. 22. World Bank, Washington, D.C.

Mathur, S.P. (1980): **Underground mine mechanisation: Appropriateness of intermediate technology for coal industry.** National Seminar on Mining Policies and Programmes, Central Mining Research Station, Dhanbad, India, 23 November.

Mattos, M.C. (1985): National hydrogen energy programme in Brazil. **International Journal of Hydrogen Energy** 10(9)601-606.

McCaslin, J.C. (ed) (1983): **International petroleum encyclopedia.** PennWell, Tulsa, Okla.

McNelis, B. and P. Fraenkel (1984): **Solar and wind technologies for developing countries: Current status and anticipated development.** Energy Research Group, Ottawa.

Meier, R.L. (1974): **Planning for an urban world: The design of resource-conserving cities.** MIT Press, Cambridge, Mass.

Menard, H.W. (1971): **Science: Growth and change.** Harvard University Press, Cambridge, Mass.

Merriam, M. (1984): **Use of wind for electricity generation.** Energy Research Group, Ottawa.

Meta Systems Inc. (1980): **State-of-the-art review of economic evaluation of non-conventional energy alternatives.** Report prepared for the U.S. Department of Agriculture. Meta Systems Inc., Cambridge, Mass.

Meta Systems Inc. (1982): **An examination of the substitution of woody biomass based fuels for oil in the industrial sectors of Costa Rica.** Meta Systems Inc., Cambridge, Mass.

Metals Society, The (1981): **Energy-conscious iron- and steel-making.** Proceedings of an international conference organized by the Metals Society, London, and the Verein Eisenhutte Österreich, Leoben, at the Montanuniversitat, Leoben, Austria on 21-14 April 1980. The Metals Society, London.

Meyers, R.A. (ed) (1983): **Handbook of energy technology and economics.** John Wiley and Sons, New York.

Mintzer, I. (1984): **Status assessment of solar photovoltaic technology.** Energy Research Group, Ottawa.

Mizrahi, A. and A.L. Van Wezel (ed) (1983): **Advances in Biothechnological processes. Volume 1.** Alan R. Liss, New York.

Moavenzadeh, F. and D. Geltner (1984): **Transportation, energy and economic development: A dilemma in the developing world.** Elsevier Publishing, Amsterdam.

Mohan, N. et al. (1981): **Techniques for energy conservation in AC motor-driven systems.** Electric Power Research Institute, Palo Alto, Cal.

Moles, F.D. (1984): The economic management of energy in the world's cement industry. In A. Reis et al. (ed) (1984): **Energy economics and management in industry: Proceedings of the European Congress, Algarve, Portugal, 2-5 April 1985: Volume 2: Energy Management.** Pergamon Press, Oxford.

Mortimer, G. (1984): **Issues in natural gas production and utilization.** Energy Research Group, Ottawa.

Mubayi, Vinod and Peter M. Meier (1981): **Energy models for developing countries: A comparative assessment.** Brookhaven National Laboratory, Upton, N.Y.

Mudahar, Mohinder S. and Travis P. Hignett (1982): **Energy and fertilizer: Policy implications and options for developing countries.** International Fertilizer Development Center, Muscle Shoals, Ala.

Muller, M. et al. (1982): **Energy technology systems analysis project summary report on technology characterizations.** International Energy Agency, Paris.

Munasinghe, M. (1979): **The economics of power system reliability and planning.** Johns Hopkins University Press, Baltimore, Maryland.

Munasinghe, M. (1980a): Integrated national energy planning (INEP) in developing countries. **Natural Resources Forum** 4(4)359-373.

Munasinghe, M. (1980b): An integrated framework for energy pricing in developing countries. **The Energy Journal** 1,1-30.

Munasinghe, M. (ed) (1980c): **Energy in Sri Lanka.** Sri Lankan Association for the Advancement of Science, Colombo, Sri Lanka.

Munasinghe, M. (1983a): **Electric power system economics: The state of the art.** Seminar on Energy Research Priorities, Ottawa, 8-10 August 1983.

Munasinghe, M. (1983b): Third world energy policies: demand management and conservation. **Energy Policy** 11(1)4-18.

Munasinghe, M. (1984a): Energy strategies for oil-importing developing countries. **Natural Resources Journal** 24(2)351-368.

Munasinghe, M. (1984b): **A framework for establishing energy research and development (R&D) policies and priorities in a developing country.** Energy Research Group, Ottawa.

Munasinghe, M. (1985): **Integrated national energy planning (INEP) using microcomputers.** Proceedings of the United Nations Conference on Energy Planning with Microcomputers, United Nations, New York.

Munasinghe, M. and J.J. Warford (1978): Shadow pricing and power tariff policy. In M. Munasinghe and J.J. Warford (1978): **Marginal costing and pricing of electrical power.** Canadian Electrical Association, Montreal.

Munasinghe, M. and J.J. Warford (1978): **Marginal costing and pricing of electrical power.** Canadian Electrical Association, Montreal.

Munasinghe, M. and J.J. Warford (1982): **Electricity pricing: Theory and case studies.** Johns Hopkins University Press, Baltimore, Maryland.

Munasinghe, M. and W.G. Scott (1982): **Energy efficiency-optimization of electric power system losses.** The World Bank, Washington, D.C.

Munasinghe, M. and G. Schramm (1983): **Energy economics, demand management and conservation policy.** Van Nostrand Reinhold, New York.

Munasinghe, M. and S. Rungta (ed) (1984): **Costing and pricing electricity in developing countries.** Asian Development Bank, Manila.

Munasinghe, M. et al. (1985a): **Microcomputers for development. Issues and policy.** Computer and Information Technology Council of Sri Lanka, Colombo, and National Academy of Sciences, Washington, D.C.

Munasinghe, M. et al. (1985b): **Optimizing rural electrical supply.** The World Bank, Washington, D.C.

Mwandosya, M.J. et al. (1983): **Proceedings of the regional workshop on energy for development in eastern and southern Africa. Volume II. Workshop papers.** Regional workshop on Energy for Development in Eastern and Southern Africa, 4-13 April, University of Lund, Lund, Sweden.

Nader, C. and A. B. Zahlan (ed) (1969): **Science and technology in developing countries: Proceedings of a conference held at the American University of Beirut, Lebanon, 27 November - 2 December, 1967.** Cambridge University Press, London.

Natarajan, I. (1985): **Domestic fuel survey with special reference to kerosene. (Volume I).** National Council of Applied Economic Research, New Delhi.

Nema, S.K. et al. (1984): "Speed" -- A solid polymer electrolyte electrolyzer development programme for electrolytic generation of hydrogen. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V,** Vol. 1, Pergamon Press, New York, 373-382.

Newbery, D.M.G. and N.H. Stern (1985): **The theory of taxation for developing countries.** The World Bank, Washington (mimeo).

Nobe, K.C. and R.K. Sampath (ed) (1983): **Issues in Third World development.** Westview Press, Boulder, Col.

Noll, Scott A. (1982): **Transportation energy conservation in developing countries.** Resources for the Future, Washington, D.C.

Obermair, G. (1984): **Comparative evaluation of nuclear power in the developing countries.** Energy Research Group, Ottawa.

O'Callaghan, P.W. (ed) (1979): **Energy for industry: a collection of scientific and engineering papers concerned with utilizing energy with maximum efficiency in industry.** Pergamon Press, Oxford.

Ocampo, R.B. (1982): **Low-cost transport in Asia: A comparative report on five cities.** IDRC, Ottawa.

Odell, P.R. (1984): The oil crisis: Its nature and implications for developing countries. In D.C. Ion et al. (1984): **The oil prospect.** Energy Research Group Manuscript Report, ERG-MR1e. Energy Research Group, Ottawa. 23-45.

Odum, H.T. (1971): **Environment, power and society.** John Wiley and Sons, New York.

Odum, H.T. and E.C. Odum (1976): **Energy basis for man and nature.** McGraw-Hill.

Ohta, T. et al. (1985): Hydrogen production from water: Summary of recent research and development presented at the Fifth WHEC. **International Journal of Hydrogen Energy** 10(9)571-576.

Openshaw, K. (1984): Personal communication based on Bialy (1979).

Organizacion Latinoamericana de Energia (1981): **Balances energéticos de America Latina.** Quito.

Organization for Economic Cooperation and Development (1973): **Proceedings of the symposium on techniques of improving urban conditions by restraint of road traffic.** OECD, Paris.

Organization for Economic Cooperation and Development (1984a): **External support for energy development in developing countries.** W.31620. Organization for Economic Cooperation and Development, Paris.

Ostrovski, C.M. et al. (1985): New developments in fuel ethanol production by gaseous anhydrous hydrofluoric acid (HF) hydrolysis of hardwood Populus Tremuloides. In H. Egnéus and A. Ellegård (ed) (1985): **Bioenergy 84: The proceedings of an international conference on bioenergy held on 15-21 June 1984 at the Swedish Trade Fair Centre, Göteborg, Sweden. Volume III: Biomass conversion.** Elsevier Applied Science Publishers, Barking, England, 181-187.

Ozatalay, S. et al. (1979): Energy substitution and national energy policy. **American Economic Review** 69(2)369-371.

Parra, F.R. (1983): Petroleum exploration in the developing countries 1971-1981: Results and expectations. Paper presented at the Eleventh World Petroleum Congress, London, for a panel discusson on: World reserves of crude oil. **Preprint of the Eleventh World Petroleum Congress, PD11.** John Wiley and Sons, Chichester, U.K.

Passmore, R. and J.V.G.A. Durnin (1955): Human energy expenditures. **Physiological Reviews** 35:801-840.

Pathak, B.S. et al. (1980): **Energy balance and utilization of agricultural waste on a farm.** Department of Processing and Agricultural Structures, College of Agricultural Engineering, Punjab Agricultural University, Ludhiana, India.

Patterson, W.C. and R. Griffin (1978): **Fluidized bed energy technology: Coming to a boil.** Inform, New York.

Pavitt, K. (1984): Sectoral patterns of technical change: Towards a taxonomy and a theory. **Research Policy** 13(6)343-374.

Peng, S.S. and H.S. Chiang (1984): **Longwall mining.** John Wiley and Sons, New York.

Perry, A.M. et al. (1982): Energy supplv and demand implications of CO_2. **Energy** 7(12)991-1004.

Piepers, G.G. (1985a): Wind energy: Current status and prospects. In E. Bilgen and K.G.T. Hollands (ed) (1985): **Intersol 85: Extended abstracts: Biennial Congress of the International Solar Energy Society, June 23-29, 1985, Montreal, Québec.** ISES/SESCI, Montreal, Québec.

Pimentel, D. (1980): **Handbook of energy utilization in agriculture.** CRC Press, Boca Raton, Fl.

Pindyck, Robert S. (1979): Interfuel substitution and the industrial demand for energy: An international comparison. **Review of Economics and Statistics** 61(2)169-179.

Poersch, W. and G. Zabeschek (1980): Fluidized combustion of fuels with different ash contents. In the Institute of Energy (1980): **Fluidized combustion: systems and applications.** Institute of Energv Symposium Series No. 4, Volume III. Graham and Trotman, London. IA-4-1--IA-4-9.

Poleman, T.T. and D.K. Freebairn (ed) (1973): **Food, population and employment. The impact of the Green Revolution.** Praeger, New York.

Pollak, Robert A. and Terence J. Wales (1978): Estimation of complete demand systems from household budget data: The linear and quadratic expenditure systems. **American Economic Review** 68.348-359.

Postel, S. (1984): **Air pollution, acid rain, and the future of forests.** Worldwatch Paper 58. Worldwatch Institute, Washington, D.C.

Price, W.J. and L.W. Bass (1969): Scientific research and the innovative process. **Science** 164(3881)802-6.

Pryor, Frederick L. (1977): **The origin of the economy: A comparative study of distribution in primitive and peasant economies.** Academic Press, New York.

Quraeshi, S. et al. (1984): Wind turbine generators: State-of-the-art. **Solar and Wind Technology** 1(1)37-48.

Ramanathan, V. et al. (1985): Trace gas trends and their potential role in climate change. **Journal of Geophysical Research** 90(D3)5547-5566.

Ramaswamy, N.S. (1979): **The modernization of the bullock-cart system and the management of animal energy resources: Background papers to an address delivered on January 22, 1979 at the 39th Annual Meeting of the Indian Roads Congress, Bangalore.** Indian Institute of Management, Bangalore.

Ramsay, W. (1979): **Unpaid costs of electrical energy: Health and environmental impacts from coal and nuclear power.** A study prepared for the National Energy Strategies Project of Resources for the Future. Johns Hopkins University Press, Baltimore, Maryland.

Ray, Ranjan (1980): Analysis of a time series of household expenditure surveys for India. **Review of Economics and Statistics** 62(4)595-602.

Reddy, A.K.N. (1978a): Energy options for the Third World - Part I. **Energy Management** 2(4)225-231.

Reddy, A.K.N. (1978b): Energy options for the Third World - Part II. **Bulletin of Atomic Scientists.** 28-33.

Reddy, A.K.N. (1985): **The energy and economic implications of agricultural technologies: An approach based on the technical options for the operations of crop production.** Working Paper 2-22/WP 149. International Labour Office, Geneva.

Reed, T.B. (ed) (1981): **Biomass gasification: Principles and technology.** Noyes Data Corporation, Park Ridge, N.J.

Reis, A. et al. (ed) (1984): **Energy economics and management in industry: Proceedings of the European Congress, Algarve, Portugal, 2-5 April 1985. Volume 2: Energy management.** Pergamon Press, Oxford.

Robinson, Joan (1947): **Essays in the theory of employment.** Second edition. Blackwell, Oxford.

Rogers, P. (1983): Irrigation and economic development: Some lessons from India. In K.C. Nobe and R.K. Sampath (ed) (1983): **Issues in Third World development.** Westview Press, Boulder, Col. 347-373.

Rolz, C. et al. (1983): Concepts on the biotransformation of carbohydrates into fuel ethanol. In A. Mizrahi and A.L. Van Wezel (ed) (1983): **Advances in biotechnical processes. Volume 1.** Alan R. Liss, New York. 97-142.

Rosa, R.J. (n.d.): **Discussion of an automotive engine designed for the direct use of low-grade fuels.** Montana State University Mechanical Engineering Department, Bozenan, Montana.

Ross, R.J.P. (1984): **Petroleum exploration and production in developing countries.** Energy Research Group, Ottawa.

Rotty, R.M. (1983): A current view of atmospheric CO_2. In P. Auer and D. Douglas (ed) (1983): **Advances in energy systems and technology, volume 4.** Academic Press, New York. 1-37.

Sabet, A.A. (1969): UAR commitments to science and technologv. In C. Nader and A.B. Zahlan (ed) (1969): **Science and technology in developing countries: Proceedings of a conference held at the American University of Beirut, Lebanon, 27 November - 2 December 1967.** Cambridge University Press, London.

Sahlins, M.C. (1972): **Stone age economics.** Tavistock, London.

Saida, T. et al. (1985): EtOH production from cellulosics. In H. Egnéus and A. Ellegård (ed) (1985): **Bioenergy 84: The proceedings of an international conference on bioenergy held on 15-21 June 1984 at the Swedish Trade Fair Centre, Göteborg, Sweden. Volume III: Biomass conversion.** Elsevier Applied Science Publishers, Barking, England. 212-219.

Sarkar, S.K. (1980): **Longwall mechanisation in India -- Intermediate vs. advanced technology -- The unsettled controversy.** Seminar on Mining Policy and Programmes, Central Mining Research Station, Dhanbad, India, November.

Sarkar, S.K. et al. (1983): Some aspects of strata control experiences at the powered support longwall face at Dheno-main colliery. **Journal of Mines, Metals and Fuels** November, 493-501.

Schilling, H.D. et al. (1981): **Coal gasification -- Existing processes and new developments.** Commission for European Communities. Graham and Trotman, London.

Schnell, R.C. and Gabor Vali (1976): Biogenic ice nuclei: Part I. Terrestrial and marine sources. **Journal of Atmospheric Science** 33(3)1554-1564.

Schramm, G. (1984): The changing world of natural gas utilization. **Natural Resources Forum** 24(2)405-436.

Scientific American (1974): **Energy and environment.** W.H. Freeman and Co., San Francisco.

Scott, W. (1984): **Optimizing electrical distribution systems.** Energy Research Group, Ottawa.

Sen, A. (1981): **Poverty and famines: An essay on entitlement and deprivation.** Clarendon Press, Oxford.

Sener, Tùlin (1977): An international comparison of demand elasticities: Empirical analysis of consumption patterns. **Studies in Development** 15.124-159.

Sexon, B. et al. (1981): Aspects of a wind energy conversion system. In J. Twidell (ed) (1981): **Energy for rural island communities.** Pergamon Press, Oxford. 153-158.

Shah, K.R. (1984): **Electric transmission technology.** Energv Research Group, Ottawa.

Shaw, D.H. et al. (1983): Recent developments in oil refining. Review paper presented at the Eleventh World Petroleum Congress, London. **Preprint for the Eleventh World Petroleum Congress, RP8.** John Wiley and Sons, Chichester, U.K.

Shaw, R.W. (1984): **The atmospheric pathway for oxides of nitrogen.** Environment Protection Service, Environment Canada. Report EPS2/TS/2. Beauregard Press, Ottawa.

Siddayao, Corazon M. (ed) (1985): **Criteria for energy pricing policy.** Graham and Trotman, London.

Siddayao, Corazon M. (1986): **Energy demand and economic growth: Conceptual issues critical to policy analysis.** Westview Press, Boulder, Col.

Siemens, Werner Von (1880): Die Elektrizitat in Dienste des Lebens. **Elektrotechnische Zeitschrift** 1(1)16-23.

Simon, Herbert A. (1957): **Models of man: Social and rational.** John Wiley and Sons, New York.

Smil, Vaclav (1983): **Biomass energies: Resources, links, constraints.** Plenum Press, New York.

Smil, Vaclav et al. (1983): **Energy analysis and agriculture: An application to U.S. corn production.** Westview Press, Boulder, Col.

Smith, K. and J. Ramakrishna (1984): **Biomass fuels and health.** Energy Research Group, Ottawa.

Smoot, L. Douglas and Scott C. Hill (1983): Critical requirements in combustion research. **Progress in Energy and Combustion Science** 9.77-103.

Srinivasan, Supramaniam (1984): Fuel cell power sources for transportation applications: Types, status and needed advances in technologies. In T.N. Veziroglu and J.B. Taylor (ed) (1984): **Hydrogen energy progress V,** Vol. 4,Pergamon Press, New York, 1717-1728.

Stewart, F. (1977): **Technology and underdevelopment.** Macmillan, London.

Strout, Alan M. (1983): **Estimating energy consumption from cross-country relationships.** Public Economics Division, Development Research Department, World Bank, Washington.

Strout, Alan M. (1984): **Energy-intensive materials and the developing countries.** Energy Research Group, Ottawa.

Strub, A.A. and G. Imarisio (ed) (1980): **Hydrogen as an energy vector. Proceedings of the International Seminar, held in Brussels, 12-14 February 1980.** D. Reidel Publishing Company, Dordrecht, Holland.

Stuckey, D.C. (1983): **Technology assessment study of biogas in developing countries.** International Reference Centre for Waste Disposals, Duebendorf, Switzerland.

Stuiver, M. (1978): Atmospheric carbon dioxide and carbon reservoir changes. **Science** 199:253.

Subba Rao, S. et al. (1981): Determination of energy costs and intensities of goods and services in the Indian economy -- An input-output approach. In Manas Chatterji (ed) (1981): **Energy and environment in the developing countries.** John Wiley and Sons, Chichester, 205-222.

Sukhatme, P.V. and S. Margen (1982): Autoregulatory homeostatic nature of energy balance. **American Journal of Clinical Nutrition** 35:355-365.

Surrey, J. and J. Chesshire (1984): **Technology and market structure in equipment for the energy industries: Coal, oil and electricity.** Energy Research Group, Ottawa.

Szalai, Alexander et al. (1972): **The use of time. Daily activities of urban and suburban populations in twelve countries.** Mouton, The Hague.

Tabor, H. (1981): Solar ponds. **Solar Energy** 27(3)181-194.

Tabors, R.D. (1984): **Recent research in electric power pricing and load management.** Energy Research Group, Ottawa.

Tata Energy Research Institute. (1983): **Energy conservation bulletin.** Tata Energy Research Institute, Bombay, India.

Taylor, J.H. (1977): Increasing the efficiency of agricultural traction and transport. In W. Lockeretz (ed) (1977): **Agriculture and energy.** Academic Press, New York. 223-232.

Taylor, Lance (1979): **Macroeconomic models for developing countries.** McGraw-Hill, New York.

Taylor, O.C. (1980): Impact of air pollutants on vegetation. In National Research Council (1980a): **Supporting Paper 8: Energy and the fate of the ecosystems.** National Academy Press, Washington, D.C.

Thomas, R.B. (1973): **Human adaptation to a high Andean energy flow system.** Department of Anthropology Occasional Papers No. 7. Pennsylvania State University, Philadelphia, Penn.

Thomas, T.H. (1981): **Rickshaws in Calcutta.** Unnayan, Calcutta.

Thomson, M.J. (1983): **Toward better urban transport planning in developing countries.** World Bank Staff Working Paper No. 600. World Bank, Washington, D.C.

Tinker, I. (1984): **The real rural energy crisis: Women's time.** Energy Research Group, Ottawa.

Tiratsoo, E.N. (1979): **Natural gas.** Third edition. Gulf Publishing Company, Houston, Texas.

Todaro, M.P. (1981): **Economic development in the Third World.** Second edition. Longman, New York.

Tokuyama, F. (1984): **Biomass technology survey in Japan.** Energy Research Group, Ottawa.

Torres, J.E. (1984): **Latin American research and development in the energy field: A review.** Energy Research Group Manuscript Report, ERG-MR5e. Energy Research Group, Ottawa.

Turner, L. (1983): **Oil companies in the international system.** Third edition. George Allen and Unwin, London.

Turvey, R. and D. Anderson (1977): **Electricity economics.** Johns Hopkins University Press, Baltimore, Maryland.

Tunnah, B.G. (1984a): **Energy use in industry.** Energy Research Group, Ottawa.

Turnham, D. and I. Jaeger (1970): **The employment problem in less developed countries.** Organization for Economic Cooperation and Development, Paris.

Twidell, J. (ed) (1981): **Energy for rural island communities.** Pergamon Press, Oxford.

Umaña, A. (1984): **Economics of energy and natural resources: Review of an expanding field of transdisciplinary research.** Energy Research Group, Ottawa.

United Nations (1981): **Report of the United Nations conference on new and renewable sources of energy.** United Nations Conference on New and Renewable Sources of Energy, Nairobi, 10-21 August 1981. United Nations, New York. Report No. A/CONF.100/11.

United Nations (1984): **1982 Yearbook of international trade statistics: Volume 1: Trade by country.** United Nations, New York.

United Nations Educational, Scientific and Cultural Organization (1956): **Wind power and solar energy: Proceedings of the New Delhi Symposium.** UNESCO, Paris.

United Nations Industrial Development Organization (1972): **Guidelines for project evaluation.** UNIDO, Vienna.

United Nations Industrial Development Organization (1983): **Energy and industrialization of developing countries: some overall and sectoral considerations.** Sectoral Working Paper Series (3). UNIDO/IS393. Vienna.

United Nations Industrial Development Organization (1985): **Use and conservation of energy in the cement industry.** Sectoral Working Paper Series No. 31. Vienna (mimeo).

United States of America (1980): Department of Energy. **Classification and evaluation of electric motors and pumps.** Washington, D.C.

United States of America (1981): Department of Energy (1981). **Batteries for energy storage.** U.S.D.O.E., Washington, D.C. DOE/CE-0152.

United States of America (1984): **Report to the Congress of the United States: An analysis of issues concerning "Acid Rain".** The Comptroller General, General Accounting Office, Washington, D.C. GAO/RCED-85-13.

University of Oklahoma (1975): **Energy alternatives: A comparative analysis.** A study of the Science and Public Policy Program. National Technology Information Service, Springfield, Va.

Uri, Noel D. (1981): Energy substitution in the Indian economy. In **Dimensions of Energy Economics**, Jai Press, Greenwich, Conn., 129-140.

Vali, G. et al. (1976): Biogenic ice nuclei. Part II: Bacterial sources. **Journal of Atmospheric Science** 33(3)1565-1570.

Van Meurs, A.P.H. (1981): **Modern petroleum economics.** Van Meurs and Associates, Ottawa.

Vanin, Vito Roberto and Gilena Maria Gil Graça (1982): **Obtençao de coefficientes de intensidade de energia (direta mais indireta) - Brasil 1970.** Instituto de Fisica, Universidade de São Paulo, São Paulo.

Vasudevan P. and G.S. Gujral (1984: Potential of underexploited weeds as bioenergy resource. In H. Egnéus and A. Ellegård (1984): **Bioenergy 84: Volume II: Biomass resources.** Elsevier Applied Science Publishers, London. 162-169.

Veziroglu, T.Nejat (ed) (1982a): **Alternative energy sources, IV, Volume 3.** Ann Arbor Science, Ann Arbor, Mich.

Veziroglu, T. Nejat (ed) (1982b): **Nuclear hydrogen biogas.** Alternative energy sources IV, Vol. 5. Ann Arbor Science Publishers, Ann Arbor, Mich.

Veziroglu, T.N. and J.B. Taylor (ed) (1984): **Hydrogen energy progress V. Proceedings of the 5th World Hydrogen Energy Conference, Toronto, Canada, 15-20 July 1984.** Vols. 1-4, Pergamon Press, New York.

Ward, G.M. et al. (1980): Animals as an energy source in Third World agriculture. **Science** 208(4444)570-574.

W , H. (1977): Desertification and population: Sub-Saharan Africa. In M.N. Glantz (ed) (1977): **Desertification: Environmental degradation in and around arid lands.** Westview Press, Boulder, Col. 165-202.

Weinberg, Felix (1975): The first half-million years of combustion research and today's burning problems. **Progress in energy and combustion science** 1.17-32.

West, J.P. and L.G. Brown (1979): **Compressed natural gas.** New Zealand Energy Research and Development Committee, Auckland, N.Z.

Weingart, J. (1984): **Solar thermal central receiver power generation technology -- Prospects for the developing world.** Energy Research Group, Ottawa.

Weisskopf, Richard (1971): Demand elasticities for a developing country. In H.B. Chenery et al. (1971): **Studies in development planning.** Harvard University Press, Cambridge, Mass., 322-358.

Wilson, C.L. (ed) (1977): **Energy: global prospects 1985-2000. Report of the workshop on alternative energy strategies.** McGraw-Hill, New York.

Winston, Gordon C. (1982): **The timing of economic activities: Firms, households and markets in time-specific analysis.** Cambridge University Press, Cambridge, England.

Wittmus, H. et al. (1975): Energy requirements for conventional versus minimum tillage. **Journal of Soil and Water Conservation.** 30: 72-75.

Woite, G. (1985): Manpower development for nuclear power in developing countries. In M. Baier (ed) (1985): **Energy and economy: Global interdependencies. Volume 5: Technologies and supply options for developing countries.** Papers presented at the Seventh Annual International Conference of the International Association of Energy Economists, Bonn, June 3-5, 1985. International Association of Energy Economists and Gesellschaft für Energiewissenschaft und Energiepolitik, Bonn.

Wold, Herman O.A. (1982): **Demand analysis: A study in econometrics.** Greenwood, London.

Woodwell, G.M. (1974): The carbon dioxide question. In Scientific American (1974): **Energy and environment.** W. H. Freeman and Co., San Francisco.

World Bank (1980a): **Energy in developing countries.** World Bank, Washington, D.C.

World Bank (1980b): **Alcohol production from biomass in the developing countries.** World Bank, Washington, D.C.

World Bank (1981): **Mobilizing renewable energy technology in developing countries: strengthening local capabilities and research.** World Bank, Washington, D.C.

World Bank (1982a): **Emerging energy and chemical applications of methanol: Opportunities for developing countries.** World Bank, Washington, D.C.

World Bank (1982b): **World development report 1982.** Oxford University Press, New York.

World Bank (1983a): **The energy transition in developing countries.** World Bank, Washington, D.C.

World Bank (1983b): **World development report 1983.** Oxford University Press, New York.

World Bank (1984a): **World development report 1984.** Oxford University Press, New York.

World Bank and Food and Agriculture Organization (1981): **Forestry research in developing countries -- time for a reappraisal.** Paper for the 17th IUFRO Congress, Kyoto, Japan, 6-17 Sept. 1981. World Bank, Washington, D.C. and FAO, Rome.

Wu, J. (1984): **Coal industry in China.** Energy Research Group, Ottawa.

Yeager, K. (1984): R&D status report: Coal combustion system division. **EPRI Journal** 9(1)43-48.

Yuan, S.W. (ed) (1982): **Energy resources and environment: Paper presented at the first U.S.-China conference, 7-12 November 1982.** Pergamon Press, New York.

Yucel, N.C. (1974?): **Toll financing of highways: Economic and financial considerations.** World Bank Staff Working Papers, No. 187. World Bank, Washington, D.C.

Yulsman, T. (1985): Greenhouse earth revisited. **Science Digest** 93(4)28.

Zimmerman, R.E. (1982): Advances in preparation. **World Coal** 8(6)69-71.